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Ethiopian Coffee—Its Significance to World Coffee Problems

Principles of Sound Right-of-Way

The Industrial Utilization of Yeast

Utilization of Cotton By-Products

Rice Production in Afghanistan

The Durra Complex in the Cultural History of Ethiopia

Indian Seed Farm

Ceylon Office of Cinchona

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Ethiopian Coffee—*Its Significance to World Coffee Problems*

Recent studies seem to confirm that Ethiopia should definitely be considered as the native home of Coffea arabica *L. Good natural conditions make this country the main exporter of this type of coffee in Africa and potentially one of the most important producers in the world. There is such a great genetical variation among the "wild" coffees that they constitute the best sources of germ plasm now available for programs of improvement of the species. Already some trees have been found resistant or immune to all the cultures of the main rust organism with which they were inoculated.*

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Introduction

Africa, which has given to the world all of the commercial species of coffee, for a number of years did not have a significant place in the trade of this commodity. In the present century, and more especially in the recent past, this continent has become more and more important as a supplier of the precious bean.

According to data compiled by the International Institute of Agriculture and the Food and Agriculture Organization of the United Nations (FAO), the contribution of Africa to world coffee production was only 1.3% in the years 1909 to 1914 but went up to 7.3% in the years 1924 to 1929, declining a little to 6.4% in the period of 1939 to 1944 (13). More recent data based only upon exportations showed that the expected exportable production in the season 1956–57 was roughly twice the average of the period 1946–47 through 1950–51. More than 22% of world exports in 1956 originated in Africa (26).

Various factors explain the increased production of the African Continent. Trade restrictions between Europe and Latin America during the two world wars and the shortage of foreign exchange in some of the main importing countries acting as a stimulus to grow more of the commodity in their overseas territories, are two possible factors.

It must be said, however, that most of the African coffees are of the Robusta type (*Coffea canephora* Pierre) while the greatest demand exists for the Arabica type (*Coffea arabica* L.). According to data of 1953, approximately three-fourths of the exportation of coffees from this part of the world was of the Robusta types (31). The proportion now may be even higher. Because of the rust disease and some insect pests in the lowlands, only a few territories of the Eastern Hemisphere have large areas where the conditions are satisfactory for the successful growing of the Arabicas. Fortunately, the great development of the soluble coffee industry in the United States has given a better market for the Robustas. It has been found that these coffees make a good blend with other types used in the manufacture of solubles.

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Most of the Arabicas of Africa are produced in Ethiopia, Kenya, Belgian Congo, and Tanganyika. Ethiopa is of special interest as it exports half the coffee of this type coming from the continent and has the climate and soil potentialities to warrant its becoming one of the world's largest producers. Recent scientific studies seem to have established that this country definitely can be considered as the native home and probably the exclusive native home of *Coffea arabica* L. This makes Ethiopia an excellent source of fundamental information and valuable breeding material. Familiarity with the ecological conditions which have favored the development of a species is of great value to the agriculturist in the choice of the best methods of growing the crop. Despite the fact that it is not always practical to reproduce exactly the conditions in which the wild plant was growing and that we must sometimes depart widely from these conditions in order to obtain higher yields, we should not forget the environmental factors which have facilitated the development and the survival of the species. Also, generally greater variations in the genetic characters of the plant are found in its native home. This is of importance to breeders in their improvement programs. Besides the taxonomic and ecological investigations, research on the parasites of the crop in its normal habitat is another aspect worthy of attention and of great practical value.

These various considerations justify the interest in Ethiopian coffee shown lately by tradesmen as well as scientists. The significance of Ethiopia to world coffee problems is fully acknowledged by the choice of its capital, Addis Ababa, as the site of an International Coffee Conference to be sponsored next year by the Food and Agriculture Organization of the United Nations.

A single, general résumé covering most aspects of interest for all those concerned with coffee appears to us as a useful publication. This résumé contains the following: recent knowledge of principal methods and areas of production, the most common coffee types of the area, the major diseases and pests, yield data, processing and quality, potentialities of Ethiopia as a coffee producer, programs of improvement of the industry, and scientific efforts to utilize the easily available germ plasm to improve the plant products. With such a wide subject range the author will concentrate on a broad review rather than on detailed aspects already or soon to be available in more specialized articles. The first-hand acquaintance of the crop gained by him during his two-year stay in the country will be widely used as well as the available literature and the information on more recent developments kindly furnished by correspondents actually engaged in work with Ethiopian coffees.

Principal Methods, Areas of Production, and Ethiopian Types

It is not known when man began to grow coffee in Ethiopia. Although there is little doubt that the species is native, we are not certain that the use of the seeds as a stimulant beverage was discovered in the African continent. There are no truly old historical records on coffee. According to Chevalier (1) the first written mention of coffee appeared in the 16th century. Early Arabian documents indicate that the plant was introduced from Africa. However, it is possible that, even though its virtues were known, its use was slightly different until the Arabs developed the type of drink to which we are now accustomed. Moreover, it is probable that, in the first years or centuries of usage, the inhabitants of its country of origin did not bother to cultivate the plant but simply collected the fruit produced by wild trees in the forest.

The lack of ancient records from Ethi-

opia perhaps may be explained by the fact that the areas from which most of the coffee forests are still found are usually "galla" territory. The Gallas did not have any written language in the past

FIG. 1. Ethiopia. Provinces and Federated State of Eritrea. Courtesy of Mr. H. Rouk.

while the Amharas, who occupy a large extent of the northern part of the country, have been for centuries in possession of a literature which was first written in Ghez and later in Amharic. To my knowledge the oldest story on coffee from Ethiopia is the one quoted by Griaule (15). This French anthropologist recalls the legend of the birth of the coffee tree attributed to a saint named Batra Maryam (Stick of Mary) who lived in the reign of Iyassou Adyam Sagad (1682–1706). According to the legend, this saint staying in the Zeghie Peninsula on the shores of Lake Tana prayed so long that his cane, stuck in the soil nearby, rooted and became a shoot which would be the first coffee tree. This seems to indicate that the plant was not known

in this district until the end of the 17th century.

I had the opportunity to visit the Zeghie Peninsula, and there the coffee trees had the appearance of definitely being planted and not a forest component as in parts of the south. Moreover, it is doubtful that they would have grown wild in this relatively dry climate. Griaule mentioned that at the time of his visit the young trees were irrigated until they reached bearing age. Unless there was a radical change of climate through the years, it is normal to assume that the first plantings were established by the monks who had an important monastery in the district.

According to the report of the French scientific mission which visited Ethiopia from 1839 to 1843, coffee was grown in various provinces of the country but not too successfully in the north (Tigre and Amhara) (28).

Now the crop is produced in many different ways under widely divergent ecological conditions and by people with diverse cultural backgrounds. It can be seen at altitudes from 1,000 meters to over 2,000 meters, in relatively dry areas where the annual rainfall does not reach 1,000 millimeters, as well as under a wet climate of about two meters of yearly precipitation.

The farmers are Africans of various tribes speaking different dialects, Arabs originating from Yemen, and a few Europeans of various nationalities.

There is no unity, therefore, in coffee growing as there was little unity in the country in general until recently, when better means of communications and the spread of education seem to have resulted in greater cultural integration between the inhabitants of the Empire.

1. The Coffee Forests. It is easy to assume that the first systematic production of coffee in Ethiopia came from wild specimens encountered in the forests in association with other plant species. Whether or not coffee can still be found easily in a truly "wild" botanical sense is open to question and has given rise to some doubts.

Ciferri (5, 6) suggested that the plants considered as wild might have come from trees which had escaped cultivation because, he inferred, coffee is not a component of the original forest but only of

FIG. 2. Inside the coffee forest of Bojjia, district of Kaffa, Province of Jimma. Dr. G. Fiumana, one of the directors of the Tana Company, Ltd.

forests of secondary growth in poor condition due to the felling of trees in the interest of cultivation or exploitation. Russ (30) stated, "I do not place any credence in the often repeated statement that Caffa is the natural home of coffee. It is not a natural component of these forests but naturalizes easily and is so widespread around the site of old plantations which often requires careful inspection and study of the forest composi-

tion to determine as much". Von Strenge (34), who lived for some time in actual coffee forests, has recently written: "The places where truly wild coffee is still to be found are, however, limited to the small areas of primary forest which still survive. Nowadays the greater part of the Kaffa forests are secondary. So-called 'wild' coffee is also found in these. The question arises whether this is really wild coffee, that is, bushes derived from wild stands in primary forest, which have survived its thinning, or from some cause escaped clearance, or whether it is secondarily wild coffee, which was planted when these areas were settled and cultivated and then remained when the settlements were again abandoned".

There is no doubt that many of the coffee trees now seen in the forest may be the remnants of previous plantings, but this does not preclude the existence of truly wild formations. It is a fact that a number of coffee forests exist, and, whether or not they consist of wild specimens, they offer conditions worthy of more thorough studies.

a. *Location, Climate and Soils.* These forests generally lie between latitude 6° and 9° N. and longitudes 34° and 40° E. This includes areas of the provinces of Wallaga, Ilu-Babor, Jimma, Gamu Gofa and Harar. Some of the best known are found in the districts of Ennarea, Jimma, Bonga, Geisha, Mizan, Tafari (Province of Jimma), Anfilo or Amphilo, Mattu (Province of Ilu-Babor), Bale (Province of Harar).

The forests are usually located at altitudes between 1,600 and 2,000 meters (the forest of Babbaca which will be discussed later is at an elevation of 1,000 to 1,300 meters). Precise data on weather conditions over a number of years are lacking in many areas of Ethiopia. An understanding of the climate of the coffee forest belt is, therefore, of a somewhat tentative nature on the basis of available data usually collected in near-by towns.

The temperature is typical of equatorial highlands, with relatively little change in the monthly mean throughout the year but with rather great fluctuations within the month or even within the day. Swain (37) quoted the means of the coldest month in the City of Jimma (close to several coffee forests) as 18° C. and of the hottest month as 21° C. Ciccarone (4) mentioned great variations in temperature within a month from 31.3° C. in January to 15.3° C. in August for the same site.

The rainfall in the forest areas is relatively heavy for Ethiopia. As an example we give summarized data for four years of observations taken at the Jimma Coffee Experiment Station (41, 42, 43, 44).

Monthly Average Rainfall in mm., City of Jimma (1953–1956)

January	24.3	July	257.8
February	60.5	August	239.4
March	91.8	September	192.0
April	195.8	October	52.1
May	115.5	November ...	41.8
June	268.3	December	47.1

Year average 1,586.4

During this time the total rainfall of each year varied from 1,456.9 mm. in 1954 to 1,798.8 in 1955. In none of the dry seasons were there more than three months with less than 50 mm. Jimma, however, receives less rain than some of the other coffee forest districts; for instance in Gore, which is only 20 miles from the Mattu forests and has an apparently similar climate, the anuual rainfall (23-year average) is over 2,000 mm. (4). For the forest of Babbaca located in the Mizan Tafari district, Fuzzi (14) reports that the rains are well distributed during almost all months of the year. The dry season is limited to two (rarely three) months, from middle December to middle February. The average rainfall, based upon four years of

observation, is between 1,800 and 1,900 mm.

There are, unfortunately, not many data on the light intensity of the "wild" coffee belt. However, some indication may be obtained from the information published by Fantoli (11) on the cloudiness of the sky of the city of Jimma during 1938. In this particular year the monthly figures went from 36% cloud cover in December to 97% in July with an annual average of 76%. On the basis of the scanty information available it may be tentatively concluded that the coffee forests are usually located in a climate where the temperature averages about 20° C. with little variation between the seasons but great fluctuations within the month and even within the day; the rainfall is well distributed with no more than three or at most four consecutive months with less than 50 mm. and a yearly total from about 1,600 to over 2,000 mm. The cloudiness is relatively high, especially during the rainy season.

Precise data on the soils of the coffee forests are also lacking. According to the general description by Logan (21), the majority of the soils of central Ethiopia are of volcanic origin. In the highlands there are two main soil types, namely, the black earths and the red and brown clays and loams. The plateau soils are, for the most part, acid. Alkaline soils are said to be rare in the highlands. The red and brown clays and loams (Duckwa), the most common soils found in the highlands, are of considerable depth and vary from red brown to dark brown and chocolate. More recently Point IV technicians have reported on soils of the Jimma area in the "wild" coffee belt. According to them these soils fall into two main categories: (1) the red clay loam soils of the mountain slopes, and (2) the gray clays of the flat valley areas. The red soils are laterites of volcanic origin. Generally they are very productive with proper management and are easy to till. The red color is characteristic of the well-drained soils, but the color becomes darker (chestnut to brown) with poorer drainage. The profile is generally deep. Excavations on the campus of the Jimma School of Agriculture have been made to a depth of thirty feet without reaching parent rock. The water-holding capacity of the upper layer is relatively low, and the soil dries out quickly during periods of infrequent rains. The subsoil retains sufficient moisture to support a retarded growth of most deep-rooted plants during the dry period. The gray soils of the valley areas are poorly drained and frequently swampy, especially during the rainy season. The clay content is high in these soils and the subsoil is definitely a heavy adobe clay (41).

According to my own observations, the coffee forests were generally on red or brown soil, probably of lateritic origin. Only occasionally were coffee trees noticed growing on gray or black soils. The few soil samples collected and tested for pH at the University College of Addis Ababa showed a pH from 5.4 to 6.0.

b. *The Plant Complex.* Coffee is found in the forests as part of a plant complex comprising species of different heights and development. According to Philippis and Senni (27) the broad-leaved tree rain-montain forest, of which coffee is a component, includes generally four stories of woody vegetation, two of trees, and two of shrubs. *Albizzia, Celtis, Chrysophyllum, Clausenopsis,* and *Cordia* constitute the upper story, from 30 to 40 meters high. *Bersama, Bridelia, Croton, Ehretia, Ekebergia, Ficus, Morus, Polygscias, Pygeum,* and *Syzygium,* are the genera of the second upper story, from 10 to 20 meters high. *Carissa, Coffea, Gymnosporia, Sideroxylon,* etc., belong to the shrub stories. I have noticed that species of *Albizzia* and *Cordia* are sometimes found associated with coffee. It is

worth mentioning, as plants of the same genera are satisfactorily used as shade trees in coffee plantations.

The forest offers very great variations in the density of the coffee trees present, their size, and their yield, as well as the number and stand of plants of other species in the complex.

c. *Exploitation of the Forests.* Shortly after acquiring knowledge of the use of coffee, some crude exploitation of the forest must have begun, perhaps first in simply collecting fallen fruits from the ground or picking them from the trees. It may be assumed that the products of the forests close to villages were first utilized for the sake of convenience. Those located in more remote parts and in some cases populated with dangerous animals were exploited much later, and some of them may still be in an almost virgin state. When man does not interfere, the forest is quite dark, and the coffee trees are spindly; they reach considerable height but produce only enough fruit to insure the survival of the species.

It must have been noticed very early that the trees which were accidentally better exposed to the sun gave a higher yield. A simple type of management which is still in use in several areas was thus envolved. Following this system most of the tall trees of the upper story are felled and the underbrush cleared. With such treatment the yields may be substantially increased. However, when the upper trees are entirely removed, the coffee plants are often subject to dieback and other diseases.

Until recent years only a minor proportion of the coffee entering the trade came from the forests because of difficulties of access and transportation. With the great improvement of the road system and the advent of the airplane, these difficulties are of diminishing importance. Although it is impossible to differentiate in statistics between the "wild" and the planted coffee, there is no doubt that the number of the former has constantly increased. This trend may soon be reversed as new plantings have steadily been made in recent years.

There has been an overestimation in some quarters of the production potential of the coffee forests. Some statements tended to give rise to the belief that a fabulous wealth of the precious commodity existed, thousands and thousands of tons waiting only to be picked. For instance, as early as 1918 Southard (32) stated: "The possible supply of Abyssinian coffee is comparatively unlimited. There are immense forests of it in southwestern Abyssinia which have never been touched". Although in a number of forests coffee trees can be found, there are not many areas of wide extension where the density of the trees is sufficient to permit commercial exploitation.

Some data from reliable sources are now available on the production potential of these stands. Turceninoff (40), who made a study of several of the coffee forests in the Kaffa Jimma Province, reports a possible yield of 150 to 200 kilos of clean coffee per hectare. In the course of a survey made by a representative of the Tana Company, after counting the fruits of a number of trees, the yield of a forest near Mizan Tafari, Province of Jimma, was estimated at 180 to 200 kilos of clean coffee per hectare. In 1954, a careful study of yields including land measurements made in the forest of Cuti, which is under the management of the same company, showed that the average yield per hectare reached 335 kilos of clean coffee in that part of the forest under exploitation. However, in a concession covering an area of over 700 hectares, only 60 hectares could bring immediate commercial returns.*

This demonstrates the great variation in yielding ability in the forest. It is

* Fiumana, G. Tana Company Limited, Addis Ababa. Private communication, 1954.

only in rare cases that large areas offering a good production can be found in a single block. From an economic standpoint it seems better to restrict exploitation to spots where the density of trees is great enough to justify it.

Although there are a number of publications on the growing of coffee, none is available on the exploitation of coffee forests; no systematic research work exists to guide us on the best procedures in this respect. The Tana Company has been pioneering in this field. Recently Fuzzi (14) has written a comprehensive report on their first years of exploitation, and, due to the newness of the topic, it is felt worthwhile to summarize its high points. The company has a concession of about 5,000 hectares of forest at Babbaca in the district of Mizan Tafari, Province of Jimma, about 280 kilometers southwest of the City of Jimma and 28 kilometers from the airport of Mizan Tafari. The company is planning to improve 240 hectares of forest.

The ground is slightly rolling with altitudes from nearly 1,000 meters to 1,300 meters in a distance of about ten kilometers. The zone is well forested; high trees include species of the genera *Albizzia*, *Pygeum*, *Croton*, *Mamilcara*, and *Cordia*. The soil is of the red type already mentioned and is covered with a thick layer of humus. Rainfall is well distributed with a dry season of two, rarely three, months and an average between 1,800 and 1,900 mm. The temperature is warm, oscillating between 13° and 28° to 30° C.

FIG. 3. Coffee trees about three years after transplantation from the forest undercover. Babbaca, Tana Company, Ltd. Photo courtesy of Dr. G. Fiumana.

Throughout the forest there are formations of coffee growing spontaneously in varying densities. These plants are

relatively young, generally not over eight to nine years old. A few formations of old trees exist, some of which have stems with a diameter of 15 to 20 centimeters, with healthy trunks and optimum vegetative growth. The fruit production of older plants is low. The various coffee trees of the forest under story usually present the following characteristics: very etiolated growth, lateral branches long and limited to the terminal part of the plant, very long internodes, leaves of great dimension, scarce flowering and fruiting. No signs of disease were noticed on these trees.

The Company included in its valorization program only the areas which showed a density of not less than 1,000 plants to the hectare. This program included the following steps: 1. removal of the underbrush; 2. cleaning of the ground; 3. thinning of the trees of the upper story where there was excessive shade; 4. thinning of the coffee trees where they were too close together; 5. filling empty spaces with seedlings collected in the forest (nursery plants are to be used later); 6. bending of the trees still having flexible stems to insure formation of new shoots; and 7. stumping of the trunks too big to be bent.

FIG. 4. In the background, old coffee plantation shaded with "Sasso" *Albizzia* sp. Zeghie Peninsula, Province of Gojjam.

Although bending proved satisfactory, better results were obtained from stumping which produced plants of a more regular shape and higher output than those bent over. A comparison of different types of planting material coming from the forest used to fill in empty spaces indicated that best results were obtained from two-year-old seedlings with or without a ball of earth but cut back at 15 cm. from the collar. These

plants showed a good fructification the third year after being set in the field.

Good observations were also made on the effect of shade upon the coffee. It was found that not only the type and intensity of shade were of importance but, above all, the height of the shelter tree. Among the various trees present in the forest, the *Albizzias* are considered the best suited for shade. All the plants set in full sun, and even more, those grown previously under shelter and later exposed to the sun by removal of the upper story of trees showed widespread symptoms of attacks of *Hemileia*. In contrast, the well-shaded plants did not show any indication of the presence of the disease.

There is no doubt that we still need much more information on the coffee forests of Ethiopia. A great deal can then be learned about the species and its behavior under natural conditions. Time is running out for this type of study, however, as most of the forests are in process of transformation, and soon none will be left in the primitive or semi-primitive state for a comprehensive investigation.

2. Old Coffee Plantations. There are some coffee plantations established many years ago which sometimes seem difficult to distinguish from the forests. Those are found especially in the Provinces of Jimma and Sidamo and in the Zeghie Peninsula, Province of Gojjam. The trees are set at various distances, heavily shaded, left unpruned, and in general grown with the minimum of care. Similar methods of production are used in some parts of Latin America, for instance, the West Indies, the Department

FIG. 5. Small orchard in the eastern part of the Province of Arussi. In this area the coffee orchards are not as well tended as those of Harar.

of North Santander of Colombia, and the Department of Santa Cruz of Bolivia. The yields are generally low under such conditions. Although this type of plantations is found only occasionally in the Province of Jimma, it appears to be the main source of coffee of the Provinces of Sidamo and Gojjam.

3. Orchards of Harar. In the Province of Harar coffee is grown as an orchard crop. The type found there probably was introduced by the Arabs when they overran the country in the 15th century and occupied the province (32). It would then be a case of reintroduction if we accept the premise that coffee in the Arabian peninsula originally came from other parts of Ethiopia. Certainly, after visiting Yemen and Harar, one is struck by the similarities in the method of cultivation, and there does not seem to be any doubt that this method was brought across the Red Sea as it is not used in other parts of Ethiopia.

The numerous trees found just outside the wall of the City of Harar are typical of these orchards. These plantings receive great care, although one may doubt the wisdom of some of the operations. The trees are set at a distance of about 3.5×3.0 meters, several seedlings being set in the same hole, as in Yemen and Brazil (35), often making a composite "tree" with two or three plants. The seedlings are set in wide trenches about 30 cm. deep. No shade is used. The adult plants may reach a height of five meters and are not pruned until they reach 20 or 25 years when they are sometimes stumped and a new cycle of growth starts. Picking is carefully done, only the ripe cherries being collected before they fall on the ground.

Similar methods are used in the Chercher district of the Province of Harar. There are also many small orchards which do not seem to be as carefully tended as those closer to the city.

4. Small Plantings Around Huts. As in several other countries, there are many small plantings around the dwelling of the small farmers where the trees are easily fertilized with ashes and kitchen refuse. These may be found in various provinces, even in those of adverse ecological conditions where the crop is of minor importance. The care received by the plants varies according to the districts; they are usually unpruned and unshaded (except those sheltered by buildings).

5. Relatively Modern Estates. In the past 30 years or so a few plantations were established in an attempt to follow the methods used in the Belgian Congo and several parts of British East Africa. These represent a relatively small acreage, and most of them are found in the Provinces of Arussi, Sidamo, and the Chercher district of Harar. The trees are usually pruned to a single stem and grown without shade. The yields are generally low due to less favorable ecological conditions than those in the "wild" coffee belt.

6. Ethiopian Coffee Types. There is general agreement as to the existence of great variability in the coffee of Ethiopia (9, 34, 36, 42). In fact, this is considered to be one of the indications that *Coffea arabica* originated in this area. The presence of numerous types of coffee has been recognized for a number of years although a thorough taxonomic survey is still lacking. The various type classifications proposed are still tentative, as all the coffee-producing districts have not been explored for this particular purpose. A complicating factor in the classification of species growing under widely different ecological conditions is the difficulty of distinguishing between the effects of environment and those of genetic constitution. The collections established in single stations will help to determine how far climatic differences alter the expression of the germ plasm.

All the information available indicates that there is only one species of *Coffea* in Ethiopia as all the plants of the genus so far identified by reliable informants seem to belong to *Coffea arabica* L. However, there may be several botanical varieties.

Chevalier (3) judged the specimens he saw sufficiently different from the other types described to justify establishing a new botanical variety he called *Coffea arabica* L. var. *abyssinica* Chev. In his work he used a specimen of Quartier Dillon and one of W. Schimper, both collected in the middle of the past century. He mentioned as main differences from other varieties with normal fruits and leaves the fact that the plant was growing spontaneously and that its fruits were borne on long pedicels. He quoted as synonyms the following names: *Coffea laurifolia* Salixb. and *Coffea pedunculata* Roxb. An illustration of this variety is given in another publication of the same author (2).

Among the earlier workers, Spaletta (33) gives one of the more detailed classifications of Ethiopian coffee types. Unfortunately, this classification is based almost uniquely upon the beans. The author recognized four main varieties:

FIG. 6. View of one of the relatively modern coffee estates near Shashamana, Province of Arussi.

1. The Ennaria or Naria is a wild type characterized by small beans of a nice green color and exquisite aroma. This variety is subdivided into two sub-varieties: the Kaffa, with smaller dark green beans and the Ennaria proper with longer beans of light green color. Spaletta considered this variety as the original type of all coffees, not only in Ethiopia, but throughout the world. 2. The Arraro or Arrarino, has bigger seeds and

is subdivided into variety Arraro or "Long berry Harrar" with more elongated beans and Ittu with smaller beans. 3. The Zeghie has big, flat beans, less rounded than the others. 4. The Gentel is considered different more because of its preparation than by its inherent qualities.

Sylvain (36), in a tentative classification of the main coffee types of Ethiopia, cites:

1. Ennarea or Ennaria, a green variety of some similarity to *Coffea arabica* L. var. *abyssinica* Chev., characterized by the large size of the fruits, from 14 to 21 mm. in length and from 9 to 17 mm. in width. The beans are from 7 to 13 mm. long and from 3 to 9 mm. wide. This type is well distributed in the district of the same name.

2. Jimma or Kaffa, the coffee most commonly found in the forests. It is characterized by a calyx which is more developed than those of other varieties and which adheres to the fruit until maturity. The only type of *C. arabica* possessing a foliaceous, persistent calyx is *Coffea arabica* L. var. *goiaba* T., originally described by Taschdjian (39). According to de Wildeman (46), the presence of this type of calyx connects the *Eu-Coffea* types with the genera *Psilanthus* and *Psilantopsis*, species of which always show more or less foliaceous calices. He sees in var. *goiaba* the reappearance of a characteristic belonging to the ancestors of *Eu-Coffea*. Krug and Carvalho (20) also presumed that the presence of a well-developed calyx is a primitive character, the normal rudimentary calyx as found in other representatives of the genus having developed through mutation. In the case of the Jimma type the sepals are not longer than two or three mm., while those of var. *goiaba* reach five to ten mm. It is interesting to consider that this characteristic exists in coffee forest trees, seemingly indicating that trees whose flowers have large calices are more primitive than the commonly cultivated varieties.

FIG. 7. Young tree of the type S3. Jimma.

Measurements of the angle of the base, the length-width index, and length of the blades of the leaves of this type would suggest a closer relationship to *Coffea arabica* L. var. *Bourbon* (Choussy) B. Rodr. than to *Coffea arabica* L. var. *typica* Cramer. It might be, therefore, that *typica* has originated from *Bourbon* and not *Bourbon* from *typica*, as generally assumed.

There is so much variability, however, that in the same forest we may find trees looking more like *typicas*, others more like *Bourbons*, and some which are difficult to assign to either of these two main types.

3. Agarro or Agaro, a type somewhat similar to Jimma but seen only in plantations. It does not have developed calices and generally seems to have larger leaves.

4. Cioiccie, quite similar to the preced-

ing variety in vegetative habits but different in the shape of the fruits and seeds, which are roundish, with an index between length and width in the neighborhood of 1.

5. Irgalem, a rather small-leaved, green-tipped type with a bushy habit, common near the city of the same name, capital of the Province of Sidamo.

6. Dilla, a bronze-tipped, rather large-leaved type common in the district of this name, Province of Sidamo.

7. Arba Gougou red-tipped, a mutation similar to *Coffea arabica* L. var. *purpurascens* Cramer. It shows the typical reddish color of the young flushes. These trees are scarce, and only a few were seen at the Arba Gougou plantations. They are also reported at the Baca plantation in the Province of Harar. This mutation was not observed in the forest.

8. Harrar or Harar, a notably rank grower, good producer, but susceptible to several diseases, bronze-tipped with leaves sometimes very large, cultivated mostly in the Province of Harar. This is probably the best known Ethiopian coffee. It is generally considered as the best type in the country, and efforts have been made to use it in most of the estates where more care is given to the crop. Its high susceptibility to *Hemileia* and *Cercospora* has obvious disadvantages.

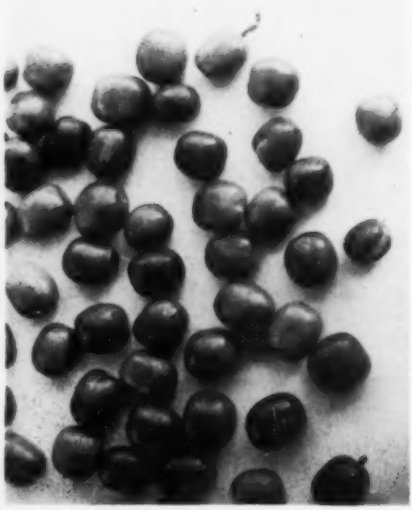

FIG. 8. Fruits of the type S 16 Wollamo showing their typical rectangular shape.

9. Zeghie, a type similar to Ennarea. The fruits are smaller, but this may be due to the drier conditions of growth on the shores of Lake Tana. There, Zeghie produces its main crop in March, several months later than the types grown in the South. It is not known whether this is due to environmental or genetic factors.

10. Loulo, a type purportedly containing a high percentage of fat in the pulp and a low ratio of clean coffee from fresh cherries. No reliable studies have been published on the matter. It is reported to be common in the district of Loulo, Province of Sidamo.

11. Wolkitte, a rank grower having some similarity to the Harar type. It has large leaves and is green-tipped. Found in the Province of Shoa, but said to have come from the Province of Gamu-Gofar in the southwest.

12. Wollamo, a type with both bronzed and green tips occurring in the same locality. The rectangular fruit with a flattened apex characterizes Wollamo.

Main Diseases and Pests

Diseases and pests do not seem to be a problem in the coffee forest where man has not changed the biological equilibrium. In only one instance have I seen cases of *Hemileia* under good forest cover: at Aroma, at an altitude of 1,400 meters which is low for most coffee forests. It has already been mentioned, however, that at an even lower elevation, at Babbaca, this fungus is of no importance under natural conditions. On

the other hand, in forests where much of the upper story has been felled and the yield stepped up, as well as in commercial plantings, pathogenic organisms may play havoc with the crop.

The leaf rust caused by *Hemileia vastatrix* B. and Br. is probably the worst potential enemy of the crop in Ethiopia as elsewhere in Africa. However, as most of the crop is grown above 1,600 meters, the disease is not as dangerous as it might be at lower elevations.

The effect of altitude upon rust infection has been noted by various investigators. Costantin, for instance, mentioned, in relation to Kenya, that coffee-growing did not give any profit below 1,200 meters due to rust attacks; if the rains and high temperatures favored the growth of the tree, the fungus profited even more and had the advantage. At altitudes between 1,500 and 1,800 meters there is equilibrium between the two organisms. At 1,800 meters and higher the coffee tree has the advantage. This does not mean that the pathogen is suppressed, it is always present, but does no harm (8).

Another factor which may reduce the intensity of *Hemileia* attacks in Ethiopia is that many trees seem to possess factors of resistance to at least some races of the fungus. This will be discussed in more detail later. The Harar type, which is very susceptible to the rust, is more of a problem in the plantations of trees of this type. Even though it may not be serious, the disease may be seen in most coffee districts of the country. During my stay I was able to identify it in the following districts: Arba Gougou in the Province of Arussi, Jimma, Agaro, Kaffa and Limu Ennarea in the Province of Jimma; Chercher in the Province of Harar; Mattu in the Province of Ilu Babor; and Dilla in the Province of Sidamo.

Other diseases are not generally widespread but limited to particular districts or conditions. *Cercospora* sp. and *Colletotrichum coffeanum* Noack (*Gloeosporium cingulatum* S. and V.S.) often may be found on coffee in the sun but does not appear to be serious. I noticed a disease, still unidentified, which caused rapid death of the tree in the district of Ghimbi, Province of Wallaga. It seemed to be caused by an infection of the vascular system and was found only in one district in low areas with poor drainage. Another disease caused some concern in a plantation of the Province of Sidamo. Although the typical signs of *Colletotrichum coffeanum* were evident, the infection appeared to be related primarily to the poor physiological status of the trees resulting from unfavorable soil conditions. Fuzzi (14) mentions the presence of a root disease in the Babacca forest assumed to be caused by a *Fusarium*.

Among the insects the most widely distributed pest seems to be a leaf miner, probably *Leucoptera* sp. A berry moth may also be found in forests as well as in plantings. A black stem borer (*Apate* sp.) was seen by the author in the district of Ghimbi, Province of Wallaga, and has been reported elsewhere. Scales and fruit flies are occasionally found.

The presence of the bean borer *Hypothenemus* (*Stephenoderes*) *hampei* Ferr. has not been definitely established. Some planters believed they had detected damages caused by this insect, but they may have been mistaken as no entomologist has yet confirmed the fact. If the insect exists at all, it must be kept well in check by parasites, otherwise it would be more in evidence.

Harvesting, Processing, Quality and Grading

1. Harvesting and Methods of Processing. As with the methods of growing, the methods of picking and processing vary from district to district. In the forest and old plantations of the southwest, the cherries are collected only once

or twice when most have ripened. A mixture of dried, ripe, and immature fruits may result from this practice. In the orchards in the vicinity of the City of Harar, selective picking is used; a series of harvestings occur as the fruit reaches the right stage. This practice, coupled with rapid drying facilitated by the low atmospheric humidity, is probably responsible for the higher quality of coffees coming from the district. It is said that green cherries are sometimes sold on the local market to be consumed with milk.

Until recently, and with the exception of the products of a few plantations, the cherries of all districts were dried on the soil (sometimes on mats). After a few days they were hulled at home with flails, stones, pieces of wood, pestles and mortars, or any other means facilitating the removal of the husks from the beans.

Great progress in processing resulted from the foundation in 1950 of the Tana Company, Ltd. This firm imported and built a number of hullers and established several processing plants for dry cherries in various parts of the country. It also used mobile equipment with hullers mounted on trucks which could penetrate remote territories. In the first year of operation, 11,000 metric tons of dry cherries were processed. This not only facilitated and improved the marketing of the product but also released labor previously occupied in the tedious slow hand hulling. The "Plantations d'Abyssinie", a group of coffee estates established some 30 years ago by a Belgian concern and now owned by the Ethiopian government, was for a long time the only establishment having facilities for processing by the wet method. In 1952 a coffee spe-

FIG. 9. Transport of coffee cherries in bags to the processing mill by means of ox-cart. Minneh Plantation, Province of Arussi.

cialist was sent to Ethiopia at its government's request by the Food and Agriculture Organization of the United Nations (FAO). He recommended that, in addition to improving the dry method of processing, the wet method be introduced in certain areas of the country, both by the establishment of factories and by the sale at cost of hand pulpers to small producers. Also in 1952, Point IV began its operations in Ethiopia and showed great interest in coffee as part of its agricultural program. Later, the Development Bank of Ethiopia, financed by the International Bank of Reconstruction, initiated a program to improve coffee quality.

With the help of these various organizations, the production of washed coffee is now increasing. During the 1956 season the Point IV coffee processing advisor installed 40 units for the preparation of coffee by the wet method.

In this way, they processed a little over 230 metric tons of a finished product of so much better quality that it sold at a premium of 20 cents U.S. higher than the ordinary kind (44). Too, several of the exporting firms have imported large equipment for wet processing, including the Tana Company which has established two factories at the sites of the forests they exploit.* Another plant with a capacity of 250 tons of green coffee has been built by the Development Bank. Moreover, 200 hand pulpers of Bentall type have been sold to small producers.

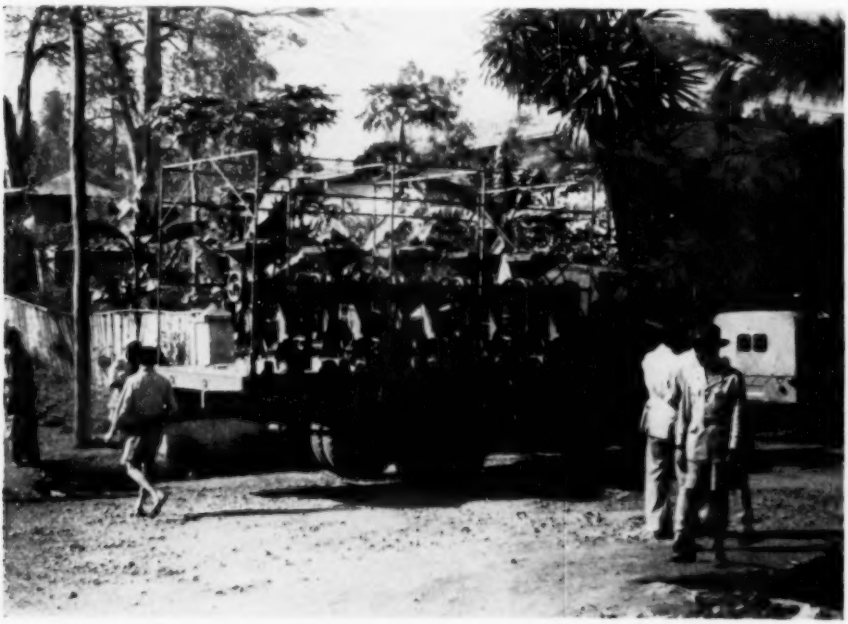

FIG. 10. Mobile equipment used by the Tana Company, Ltd., to hull coffee in husks.

2. Quality. The term "coffee quality" is rather complex and includes a series

*G. Fiumana Tana Company, Ltd., Addis Ababa, private communication, 1957.

of characteristics of a physical as well as of a chemical nature. By those of a physical nature we mean the general aspect of the product as determined by size, shape, uniformity, freedom from visible defects, and other external traits. In the past these were the only criteria used by merchants on the world market. Chemical characteristics include factors like aroma, flavor, body, and acidity, which vary according to chemical processes occurring within the bean. Color has the peculiarity of being an external trait but governed by chemical changes.

The exact nature of some of the processes affecting coffee quality is not well known, but by the method of cup testing, it is possible to appraise characteristics which cannot be determined by mere sight. Those are sometimes called "liquoring properties". Cup testing is done by experts who smell and sip coffee which has been roasted and ground in a standard way and immersed in hot water. The experts are thus able to detect all bad and good flavors and aromas and thereby establish the liquoring quality, the final expression of the value of the product. The modern tendency is to rely more on cup testing than anything else to determine quality. On the United States market, the blending and the prices of different sorts are mostly dependent upon the results of this operation. In several European countries, where coffee is still sold in large quantities as roasted bean, the external appearance is more important than in the United States.

Two main factors govern coffee quality: 1. the inherent properties of the mature beans resulting from environment and genetical constitution; 2. the manner in which the beans are treated from picking to delivery on the market. The inherent property of the beans is in a way more important than the treatment factors, as it is relatively easy to change processing method while the genetic constitution and certain aspects of the environment cannot always be altered.

In Ethiopia it was the belief that, while the cultivated coffees of Harar were good, the so-called wild coffees of the south were basically inferior. In order to test this, the author prepared small samples of the wild coffee, using only ripe cherries and processing them by the wet method. These samples were sent for appraisal to the liquorer of the Kenya Coffee Board, who estimated that, after grading, most would have a market value somewhat similar to the average Kenya type. As coffees from Kenya are among the best in the world, this report indicated that the general quality of Ethiopian coffee is good.

3. Grading. In the past there was very little classification of Ethiopian coffees. The only distinction commonly made was between the Harar and the Abyssinian, including all the coffees produced outside of the Province of Harar. Nigra (23) suggested a more exact classification including:

1. Harar or Chercher, 2. Lekemti, 3. Jimma, 4. Sidamo.

At the time of my visit, from 1952 to 1954, this classification was used on the local market, Harar usually bringing a higher price and Sidamo the lowest.

In 1952 the Government, in an effort to improve the quality of the exported product, enacted regulations on cleaning and grading. These were designed to improve the physical aspect and to give a more uniform product. Size classification was made compulsory. Although designation of the origin of the products was included in the regulations, no consideration was given to the establishment of grades based upon cup quality. The Tana Company, however, has taken some steps in this direction. With the help of an expert Italian cuptaster, Dr. Ramasco Vittor, the following grades

have been established for the coffees exported by this company (12):

A. Harrari—trade mark "Lancia Scudo", including the coffees produced in the Province of Harar from authentic plantings and nationally processed.

B. Arussi—trade mark "Cavallo", produced in Chercher, formerly considered part of the Harar type. This grade also comprises products coming from part of the Province of Sidamo (near Irgalem and Wondo).

C. Sidamo—trade mark "Giraffa", includes the production from this province not incorporated in Arussi grade.

D. Jimma—trade mark "Gazzella", comprises the production of the whole province with the exception of Bonga and Mizan Tafari.

E. Kaffa—trade mark "Alfa-Serpente", includes the production of Bonga and Mizan Tafari in the district of Kaffa.

F. Lekemti—trade mark "Elefante", includes the production of the Province of Wallaga.

G. Gore—trade mark "Palma", includes the production of the Province of Ilu-Babor.

H. Washed—trade mark "Groce Copta". This name inaugurates the presentation on the market of the washed coffee from the Province of Harar. All the other types are "naturals" or processed by the dry method. It is anticipated that other trade marks may be established with an increase in production of certain districts and the wider use of the wet method of processing.

Potentialities of Ethiopia as One of the Main World Coffee Producers

In the past ten years the exports of coffee have almost trebled, rising from around 250,000 bags in 1945 and 1946 to about 700,000 in 1955 and 1956. This last figure represents about two percent of the world trade.

Several factors have contributed to this spectacular increase in exports, probably one of the most significant being the stimulus induced by the high prices of the fifties. Much of the "wild" coffee was not suitable for exploitation, as collection and transportation expenses precluded economical operation.

After the increase in market value of the product, Ethiopia was probably the only country which could rapidly increase its output without having to wait for the first yields of new plantings or for the results of changes in the management of old plantations. After World War II great efforts were made in the general development of the country; old roads were repaired and new ones opened. The airplane gave still better access to remote districts, the fares of the Ethiopian Airline being low enough to permit flying large quantities of coffee instead of using horse caravans or trucks. The figure of two percent of the world trade is still low, however, and the significance of Ethiopia in this trade lies more in its potentialities than in actual production.

Probably nowhere in both hemispheres exist such vast expanses of land so well suited for coffee production. As an example of the excellent conditions which can be found, the following is quoted from a Point IV report (42) following the visits of some of their technicians in a coffee district:

"The general area south and west of Bonga and extending in a northwesternly direction is ideally suited for intensive coffee plantation expansion. Approximately 1000 gashas * of land lying between Uosh Uosh and Kasha are capable of being planted to coffee and being developed into intensive type plantation with a minimum of expenses. This area has the greatest potential for intensive production of coffee of all the areas seen in Ethiopia thus far. Evidences of this are:

1. Soils that average five meters in depth.

* Roughly 100,000 acres.

2. Slope that averages three percent.

3. Fertility (high phosphate and potash content), slightly acid soils, and vigorous lush-growing vegetation.

4. Abundance of water in freely flowing streams with a year-round flow.

5. Evidence through artifacts of a dense population highly skilled in agriculture. These people left the area as a result of wars and not as a result of failure of agriculture.

6. The presence of wild coffee in sufficient quantities and in such an excellent state of growth as to establish the fact that good coffee can and will grow in the area".

Even if no other district equals Bonga in this respect, there is a very large acreage well-suited to coffee in the southwest as a whole, including the Provinces of Kaffa, Jimma, Sidamo Borana, Ilubabor, and Gamu Gofa. This acreage may become even more extensive if good commercial varieties, highly resistant to *Hemileia*, can be developed. Then coffee could be grown easily at altitudes much lower than those currently required to offset the effect of low elevations upon the severity of the disease.

Of course, economic, political, and sociological factors always play their role in the expansion of a crop. Great increase in production will depend on further general development of the country, including better transportation facilities and an increase in the number of skilled personnel. State policies on taxation, land availability, and trade control also will be of importance in substantial production increases. Moreover, world demands for this commodity will determine the actual development of this potential. If, due to very high supply from the two hemispheres, the price of coffee stabilizes at a relatively low value, the high cost of establishing new plantations on a large scale might preclude competition with established estates already in full production. On the other hand, under normal price conditions, taking into consideration coffee production costs starting from seed planting, Ethiopia with its good soil and climate could successfully compete with any other producing country.

In the future, if there is a shift of main coffee production from the Western to the Eastern Hemisphere, Ethiopia will play a leading role as the best possible source of Arabicas, unless a drastic change in the consuming market considerably reduces their importance.

Programs of Improvement of Coffee Production

The Ethiopian Government has shown great interest in the development of the coffee trade as a foreign exchange earner. Since the recent progress in the processing of coffee has already been discussed, only that work related to increase in production will be considered here.

As previously mentioned, the Food and Agriculture Organization of the United Nations, following a request from the government, provided in 1952 the services of a coffee expert under the general technical assistance program of the Organization. The specialist was assigned to survey and assess the value of areas producing wild coffee, to organize suitable schemes for the rational exploitation of these areas, to recommend measures for the extension of the growing of cultivated coffee, and to give general advice on improved methods of processing and marketing. The first expert served for a period of approximately two years and was replaced by another one in 1954.

Point IV began its operations in Ethiopia in 1952, its most important achievement in the field of agriculture being the establishment of the Imperial College of Agriculture. The college follows the same pattern as the Land Grant College of the United States, with activities in the field of resident teaching, research, and extension. Point IV also started an

agricultural technical school before the College could be put into operation. The Point IV technicians realized the significance of coffee in the agriculture of the country and to this end worked closely in conjunction with FAO experts and local coffee technicians.

On completion of his mission, the first FAO specialist presented a report to the Government which included recommendations for increasing the production of coffee and bettering its quality. One of the main points stressed was the need for a central organization to coordinate research, teaching, extension, promotion, and trade activities with the crop concerned. Also, the desirability of research on the management of coffee forests was emphasized especially.

The first agricultural technical school under the Point IV program was established in 1952 at Jimma, in the heart of the coffee belt. Soon, research was initiated on the crop, and the school grounds were selected as the site of the first Coffee Experiment Station. Seeds or plants from 49 types or accessions of coffee were secured through FAO, including varieties from Kenya, Tanganyika, Brazil, Guatemala, and Ethiopia. Later the various seedlings obtained were set in the field using a design permitting statistical analysis of the data. At the time of writing, the first two crops have already been harvested. In due time the available data will be of great value, not only to the Ethiopian program, but to research institutions in other parts of the world.

FIG. 11. Nursery including seedlings of a number of coffee types introduced at the Jimma Agricultural Experiment Station. Photo courtesy of Mr. N. J. Schommer.

An interesting program of selection is also in progress with about 140 trees of a forest located near the Station. Twelve trees were chosen for a more detailed study of the genetic variations to be found among wild trees. Six were clas-

sified as tall growing, three as intermediate or semi-dwarf, two as dwarf, and one as extreme or double dwarf (43). Further studies are being made. The Station also has experiments on pruning methods, mulching treatments, "sun hedgerows", and fertilizers (42).

In addition, the Point IV program in Ethiopia has given technical assistance to a Government Development Project, undertaken to provide coffee growers with good seedlings. In 1956, 188,000 seedlings were distributed to growers under this project, and 391,000 were in preparation for use in 1957 (44). Nursery grown plants of very good quality previously had been found, averaging about twice the size of seedlings of comparable age growing in the forests (43).

The Development Bank of Ethiopia has also helped the promotion of coffee production by granting long-term loans for improvement of coffee forests. The Ministries of Agriculture, Commerce, and Finances of Ethiopia are also helping in program.

The report of the first FAO expert had indicated the need of training coffee technicians at different levels to carry out the various tasks necessary to develop the industry. To this end, FAO granted fellowships to two employees of the Ministry of Agriculture, graduates of an Ethiopian agricultural school, to study methods of coffee production and processing used in the Western Hemisphere and, in general, to learn more about the crop. These fellows spent two years at the Inter-American Institute of Agricultural Sciences in Costa Rica and several institutions of Brazil and Colombia.

Point IV has been active in providing agricultural training in Ethiopia, due emphasis being given to coffee. Student assistants have contributed to the efforts necessary to carry on coffee research at Jimma. Student work leaders have conducted the field operations of planting, cultivating, picking, mulching, pruning, and other tasks necessary to maintain the coffee plantings. Students have also been quite helpful in collecting and analyzing the yield data. Student assistance is not only necessary in order to carry on the research work but is proving to be valuable training for the young men who will lead such activities in the future (17).

These various efforts should yield fruit in future years, accelerating significantly the country's coffee production if economical factors do not intervene against it.

Research on Ethiopian Coffee Types in Various Countries

Although it is now assumed that *Coffea arabica* originated in Ethiopia, most of the trees of the species which provided propagating material for large plantings throughout the world were probably introduced directly or indirectly from Arabia. Communication difficulties may explain why it took so long for research workers to profit from the wealth of germ plasm which might be expected to exist in the native home of the species. Credit should be given to Cramer for having insisted on the value of the wild forms of Arabica since his first work in Java in 1905 (10). Much later (1941), but still at a time when relatively few introductions had been made from Ethiopia, de Wildeman stated, quite rightly, that the trees common in this country merit attention not only as a possibility of defining the characteristics of the species in its center of dispersion, but also as a source of genetic material to renovate the crop in areas where diseases and other causes have notably curtailed production (46). More recently, the First Coffee Round Table, an international meeting held at San Jose, Costa Rica, in 1953 adopted a recommendation to the effect that the collaboration of a botanist and an ecologist be obtained to collect in Ethiopia and neighboring

countries specimens of *Coffea arabica* and related species of the genus (22). The immunity or high resistance to *Hemileia vastatrix* now encountered in some plants from this origin justify the interest shown in this type of endeavor. Although the expedition recommended by the Round Table did not materialize, the introduction of African coffees has been stepped up, and several stations are now engaged in their appraisal.

1. Producing Countries of the Eastern Hemisphere. The Dutch, leaders in various aspects of coffee research, were probably the first to work on Ethiopian introductions. According to Cramer (10) a note with a translation of an article on *Coffea stenophylla* G. Don in the Kew Bulletin of 1896, mentioned that in 1864 a planting of introduced Abyssinian (Ethiopian) coffees existed on Limburg Estate near Malang.

Although it is doubtful that any scientific selection work per se was done at that time, this at least indicated an interest on someone's part in investigating the value of these coffees.

In 1928, Cramer visited coffee estates in Ethiopia and, noting the vigorous healthy appearance of the plants, selected some mother trees, seeds of which he sent to Java. The resultant progenies showed a good performance in the lower Arabica zone. They suffered less from leaf disease there and were recommended for this zone; they surpassed all other kinds by their very vigorous growth and high resistance to leaf disease. After the first crop, which was quite good, the trees showed no signs of overbearing and had a dense dark green foliage and promised another good crop. None of the other kinds tested in this field gave comparable results. Later other varieties were introduced as a result of the visits of two Dutch research men to Africa (10).

A 1954 reference from Indonesia, the former Netherlands East Indies, seems to indicate success with coffees of this origin. It states that recently more and more areas have been planted with "Abessinie", a more vigorous type which is better suited to the lower lying areas where the common Arabica is not as good a producer. This type is more resistant to leaf disease and requires wider spraying and less shade. The taste and flavor of the product are not detrimental to its value on the market (16).

The first systematic introduction of Ethiopian material into Kenya apparently occurred in 1929 through the British Consul at Harar. The seeds proved to be of a homogeneous variety later named Harar. In the initial trials this type showed outstanding vigor and yield and appeared to be a most valuable acquisition. Unfortunately, the early promise was not fulfilled and because of extreme susceptibility to diseases, yield and vigor decreased. A single tree selection called S.L. 10 was made from this variety. It resembles the parent in all characteristics and has proved no better than Harar in sustaining its high yield and vigor after the first few crops. In 1936, seeds were procured from coffee forests of the Geisha and Amfillo (Amphilo) districts. The plants obtained showed great variation, as is common in all the "wild" coffees from Ethiopia. Some of them have been claimed to possess a certain resistance to coffee berry disease (18).

During the Ethiopian campaign of 1941 and 1942 three army officers from Kenya, interested in coffee, collected in various districts a number of specimens which bear the names Dalle, Dalle-Mixed, Dilla, Dilla and Alghe, Gimma Mbuni, and Gimma Galla Sidamo. All these were chosen on appearance without detailed study, for one of two reasons: that their type was not represented in Kenya or that they represented the endemic form for their particular climate. Observations of yield, climatic preference, and general characteristics of these varieties are still in their initial stages (18).

Recently data have been published on yield for a two-year variety trial with 21 selections and variations of different origins, including two introductions of Dalle-Mixed and Dilla–Alghe. These preliminary results, which so far are more indicative of earliness than sustained high productivity, revealed that Dalle-Mixed was the second highest producer with a yield significantly higher than 17 other types (7). Wellman observed the effects of *Hemileia* on the behavior of different coffee types under field conditions in various countries. The types Gimma, Dalle, and Dilla appeared to have high resistance in Kenya, while Geisha and Amphillo showed great susceptibility in the Congo (45).

Some introductions of Ethiopian coffees were also made in Tanganyika and the Belgian Congo some time ago. "Amphillo" and "Harar" coffee types were grown at the Tanganyika Station in 1936 (38). Kinds (19) mentions without more detail the introduction of a coffee called Moka from Ethiopia into the Belgian Congo. Several other Ethiopian types are growing in these two territories, but the extent of research on them is not known.

At the Mysore State Experiment Station of India some introductions were made through FAO in 1953 and 1954. These accessions, called Tafari Kela, Arba Gougou, Kaffa, Wollamo, and Irgalem, correspond to the terminology used by Sylvain (36) for their short description. R. L. Narasimhaswamy, Botanist of the Station, has kindly reported to the author in a personal letter some preliminary observations on the behavior of these types. In general development Kaffa was found to be very vigorous; Tafari Kela, Irgalem, and Ennarea vigorous; Wollamo not vigorous, and Arba Gougou very poor in growth. The following percentages of plants of different types were susceptible to *Hemileia*: Wollamo, 91.0%; Tafarikela, 65.7%; Irgalem, 64.1%; Arba Gougou, 56.3%; Ennarea, 36.7%; and Kaffa, 17.7%.

It may be worthwhile to emphasize that most of the introductions from Ethiopia are not true varieties and that there is a great genetic variation among trees. This explains why some plants coming from seeds of different trees in the same plot may exhibit susceptibility to disease while others do not. This has been well demonstrated by the research carried out on *Hemileia* in Portugal, using greenhouse specimens inoculated with the fungus.

2. **Western Hemisphere.** In the past six or seven years Ethiopian coffees have been systematically introduced in the Western Hemisphere. The pioneer work was started by Archer, then Agricultural Explorer of the Section of Plant Introduction of the United States Department of Agriculture. In 1951 this technician collected a number of coffee seeds from different parts of Ethiopia resulting in 14 accessions identified by numbers according to the filing system of the U.S.D.A. The resulting plants were forwarded later to several Stations south of the Rio Grande and are the oldest available stock of these coffees.

The FAO coffee specialist in Ethiopia made a new series of collections in 1953 and 1954. These are listed in detail by Sylvain (36).

For a number of years, Western Hemisphere technicians have been afraid of the effect of the possible introduction of *Hemileia* on coffee production in the New World. This worry was somewhat dramatized by the trip around the world in 1952 of two top Point IV technicians, Dr. F. L. Wellman and Dr. W. H. Cowgill, to gather information on the rust disease and collect, if possible, seeds of plants resistant to the fungus. Many coffee types were introduced from the Eastern Hemisphere including some originally from Ethiopia growing at the time in another country. Since then other

FIG. 12. Some of the Ethiopian coffee introductions in the variety collection of the Inter-American Institute of Agricultural Sciences, Turrialba, Costa Rica. Standing near the trees are two young Ethiopians under an FAO fellowship to study coffee production in the Western Hemisphere. Photo courtesy of Mr. P. Morin, FAO.

FAO and Point IV technicians have collected seeds of coffee in its native home. More than 100 accessions of coffees from Ethiopia are now available, and this number is continually increasing.

Since the beginning of the program all the introductions originating from the Eastern Hemisphere were made through the Plant Introduction Section of the U.S.D.A., as a precaution against the entry of some enemy of the crop, especially *Hemileia*, into our hemisphere by means of a direct importation of planting material from the East. At the International Coffee Round Table of 1953 steps were taken to organize systematically the program of introduction and distribution of foreign types (32). A recommendation was approved to the effect that the Section of Plant Introduc-

tion of the U.S.D.A. be consulted about the possibility of enlarging its installations at Coconut Grove, Florida, to include a collection of the genus *Coffea* under quarantine conditions. This has been done with financial assistance from the International Cooperation Administration of the United States (Point IV). It was also recommended that coffee collections from material of the Eastern Hemisphere be maintained in five centers of investigation in Brazil, Colombia, Costa Rica, El Salvador, and Puerto Rico, and that the Inter-American Institute of Agricultural Sciences maintain a central file in which should be registered all the existing material in the collections of various American countries. This Institute was also designated to serve as intermediary in the importation of material especially from countries outside of the Western Hemisphere (22).

The Ethiopian introductions are now growing in several experiment stations in the Western Hemisphere. Several variations from this material have been observed at the Agronomic Institute of the State of Sao Paulo at Campinas, Brazil. Genetic analyses by hybridization have started at this station, and it is hoped that precise information will be available soon *. No reports of research with Ethiopian introductions have been published.

Some of the accessions which have demonstrated resistance to *Hemileia* in Portugal and in Kenya are being propagated at the Inter-American Institute of Agriculture Sciences, Turrialba, Costa Rica. They plan to have further testing of this resistance made of the progenies. As part of a project on quality being conducted at the same Institute, the processed beans of the Ethiopian introductions are being subjected to various tests, comparing them with those from other types.

3. Portugal. The Center of Investigation of Coffee Rusts. A well organized program of testing coffee for resistance to the rusts has been in progress since 1951 in Portugal at the National Experiment Station of Sacavem under the able leadership of Dr. Branquinho d'Oliveira. Following the visit of Drs. Wellman and Cowgill to this center in 1952, it was decided to amplify the program still more by forwarding samples of the fungus and of some coffee types collected during their tour. *Hemileia* spores and coffee seeds were also received from Ethiopia through FAO. Subsequently, the program was subsidized by Point IV, and the Center of Investigation of Coffee Rusts was established at Oeiras as a branch of the National Experiment Station. It is beyond the scope of this article to describe in detail the research carried out at the center. Interested readers are referred to the paper by Oliveira covering the work on *Hemileia vastatrix* up to 1955 (24) and to the one of Rodrigues Junior on *Hemileia coffeicola* Maubl. et Rog. (29). Some up-to-date information was obtained recently from a report of Dr. d'Oliveira dealing especially with the Ethiopian types (25).

As it is known that the rusts commonly have several biological races, a plant immune to one of the races may be highly susceptible to another. This explains some of the disappointments encountered in the past with supposedly resistant varieties. The program of Portugal, therefore, included not only a wide collection of coffee germ plasm but also a number of cultures of *Hemileia* with which to test each coffee type. For Ethiopian seedlings there exists another complication in that most of the introductions are not of a fixed variety. It is necessary, therefore, to test individual seedlings from the same lot of seeds.

* Carvalho, Alcides, Chief of Genetics Section, Agronomic Institute of the State of São Paulo, Campinas, Brazil. Private communication, 1957.

More than 150 cultures of *Hemileia vastatrix* from different sources were used in these tests. These cultures were classified according to their reaction to certain hosts and placed in 6 physiological groups, or races, four of which affect *Coffea arabica* and two, other species of the genus. Interestingly enough, it was established that, as there is great variation in the Ethiopian coffees, so there is great genetic diversity in the rust fungus found there. Cultures belonging to the four groups attacking *C. arabica* could be isolated.

The various Arabica types were also classified according to their reaction to the different physiological races of *Hemileia*. Five groups were recognized:

Group A. Immune or highly resistant to all the cultures of *Hemileia vastatrix* for which they were tested.

Group B. Resistant to all the physiological races found on *C. arabica* with the exception of those *Hemileia* races of group V.

Group C. Resistant to all the physiological races with the exception of those *Hemileia* races of group III.

Group D. Resistant to all the physiological races with the exception of those *Hemileia* races of group I.

Group E. Susceptible to all the physiological races attacking *C. arabica*.

The Ethiopian accessions were among the best from the point of view of resistance. Many of them pertain to Group C, including some plants from the Irgalem, Arba Gougou, Geisha, Dilla, and Kaffa types. Plants of the Wollamo Amphilo and Dalle-Mixed type pertain to Group D. The most outstanding feature, however, is the fact that some plants issued from S.4 Agarro, S.6 Cioiccie, and 619-No. 32 accessions showed high resistance or immunity to all the cultures of *Hemileia vastatrix* with which they were inoculated. Similar results were obtained only in the case of a few Indian accessions, which are the results of a number of years of selection for resistance to the rust organism. The fact that seeds of Ethiopian origin, collected more or less at random, produce plants already showing this characteristic indicates that much can be gained from breeding programs with these types. As a comparison, plants obtained from coffee varieties generally grown in the Western Hemisphere which were submitted to the tests belonged to Group E, showing susceptibility to all the physiological races of *Hemileia vastatrix* parasites of *C. arabica*.

In the work with *Hemileia coffeicola*, no plants of *Coffea arabica* have so far shown resistance to the organism (29).

The behavior of the Ethiopian types concerning susceptibility to *Hemileia vastatrix* has a significance still greater than its impact upon control of the disease. It confirms the richness of the germ plasm available and shows that the existing genetic variation is greater than that indicated only by morphological differences. From breeding programs we may obtain precious factors from these coffees including, for instance, resistance to other disease, lower transpiration rates, better root system, higher photosynthetic rate, etc. The future of coffee breeding may lie in the development of varieties showing special physiological or anatomical characteristics which make them better adapted to specific areas, instead of trying to produce types based only upon high yield records without knowledge of their dependence upon ecological conditions.

By maximum utilization of the available genetic variation we may be able to grow the crop successfully in areas where the present standard varieties do not yield well. These programs of improvement of the species probably constitute the main significance of Ethiopian coffees to the production of this commodity all over the world.

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Utilization Abstract

Indian Seed-Fats. Utilization of many potentially useful seed-fats is not practical because of difficulties of collection, mainly the result of scattered growth. However, sometimes established industries (e.g., canning) have as a by-product large quantities of seeds. In India several such possible seed sources of oleic-rich fats are soapnut (*Sapindus trifoliatus*), papaya (*Carica papaya*), nux-vomica (*Strychnos nux-vomica*), and guava (*Psidium guajava*). The soapnut tree is cultivated in Bengal for its saponin-rich fruit that is used as a detergent. Its seeds contain 14.5% fat that is high in arachidic acid (20–22%) and oleic acid (55–60%) and could be used as a source of these acids or as a "hard" oil in soapmaking. Papaya seeds, easily removed from the widely utilized fruit, contain 24.9% fat that would be an excellent salad oil after refining. The fat contains a high percentage of oleic acid (77.3%). Nux-vomica seeds, much collected for use in the preparation of the alkaloids strychnine and brucine, yield 7% arachidic acid and 4.2% fat that could be used for soapmaking. Guava seeds, available in quantity from the rapidly expanding canning industry in India, contain 10.1% fat that is similar to Brazil nut (*Bertholletia excelsa*) and myrobalan (*Terminalia chebula*) oils. (V. V. R. Subrahmanyan and K. T. Achaya, *Jour. of the Sci. of Food and Agric. 8(11): 657–662. 1957.*) (JWT)

Principles of Sound Right-of-Way Vegetation Management

Right-of-ways occupy a vast acreage of our landscape where vegetation management is necessary. On these areas indiscriminate use of chemical weed killers is widespread even with sound ecological techniques readily available. The application of sound management would not only benefit the utility with reduced costs on a long-range basis but also result in high conservation values to the nation.

WILLIAM A. NIERING [1]

Introduction

Right-of-ways, including those of electric utilities, railroads, pipe lines, as well as roadsides, represent a tremendous acreage of our landscape where the native vegetation is being managed. It has been estimated that at least 50,000,000 acres are involved throughout the country. Prior to the advent of herbicides these areas were hand cut. However, they are now being subjected to an entirely new type of manipulation with chemical weed killers such as 2,4,5-T and other newer formulations. Since the land area involved is considerable in a country where population pressure for undeveloped land is intensifying, it seems only reasonable that management techniques should be utilized which will fulfill the needs of the agency involved and at the same time result in high conservation values. In contrast, many of our right-of-ways are being mis-managed even with applicable scientific knowledge readily available (4, 5, 9, 10, 11). In this paper the major emphasis will be on electric utilities right-of-ways. However, the general principles are applicable to all right-of-ways.

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To satisfy the utilities the easement must be free of trees which will eventually grow or fall into the lines. Moreover, they must be readily accessible, preferably by a trail, for patrol and maintenance in all weather. It is also necessary that these needs be met at a minimum annual cost. Currently, the indiscriminate blanket spray techniques which are aimed at eliminating all woody vegetation are in widespread use. By such techniques much valuable shrub cover is unnecessarily destroyed and poor root-kill of the undesirable trees frequently results. The principles set forth in this paper are aimed at manipulation of the vegetation in order that maximum shrub cover be preserved with considerable benefits both to the utility and the public.

In many cases the companies do not own these areas, but merely build and maintain facilities for their specific purpose. The land owner has all rights of ownership that do not conflict with the purposes of the easement and often has some control over the line in regard to vegetation management policies. This is especially true since the use of herbicides has become so widespread. The owner and the general public are therefore interested in these areas from the standpoint of the many values which can

be obtained by proper manipulation. Some of the values, present or potential, to those concerned are as follows *:

1. General conservation values—These values are recognized by all conservation-minded groups. They are important for the greatest social good—now and in the future.
2. Wildlife habitat—The concern of biologists in general, involving various clubs and societies. Here, wildlife includes song birds.
3. Game habitat—This is the chief interest of the various State Game Departments as well as sportsmen and sportsmen's clubs. The values of the right-of-ways are for the production of and to increase game populations and not as shooting areas.
4. Forestry values—The concern of foresters, primarily in obtaining suitable stands adjacent to the right-of-ways and removing threats of disease or insects to timber species.
5. Habitat for flowering herbs and rare plants—Of particular interest to State Botanical Societies and to professional and amateur naturalists and botanists. The preservation of species or associations that might otherwise become extinct is of primary importance.
6. Landscape and aesthetic values—The concern of Garden Clubs and the general public, especially where lines cross or are seen from public roads.

In the management principles to follow these varied interests are considered but with the needs of the utility of paramount importance.

* Taken in part from "Connecticut Botanical Society Right-of-way Vegetation Committee Paper No. 4, and Connecticut State Board of Fisheries and Game. Public Utility Right-of-ways—Vegetation Management, January, 1957".

Techniques Toward Sound Management

How can the needs of the utility be ascertained most advantageously and at the same time create a vegetation cover compatible with the interests enumerated above? Obviously the problem is of an ecological nature and requires the attention of vegetationists who can recognize the various plant communities occurring on these easements or "strip transects". After a recognition and mapping of these semi-natural communities it is possible to formulate specifications involving various techniques. Since it may not always be possible to satisfy all interests equally, variations in the treatment will accommodate those which take priority in any particular situation. If one is primarily interested in a cover for game species alone, the methods prescribed will differ somewhat from those used to create a cover with highest general conservation values.

Along any line a variety of communities exists which require a multi-technique approach. For example, through forested regions dominated by oak, tree clumps of sprout origin are usually scattered in a shrubby and herbaceous matrix. Such tree sprouts can be selectively removed and low shrub cover which may be present, such as low bush blueberry (*Vaccinium* spp.) and huckleberry (*Gaylussacia baccata* (Wang.) K. Koch) can be preserved (Fig. 1 A). Such shrubs serve as excellent wildlife food and cover and substantial evidence indicates that this dense cover tends to retard re-invasion by new tree seedlings (7, 15, 16). Other valuable taller shrubs such as bayberry (*Myrica pensylvanica* Loisel.) and high bush blueberry (*Vaccinium corymbosum* L.) can also be saved if the utility has no objections. A good trail directly under the wires, if not already present, can be established and maintained. As one moves from beneath the lines toward the forest edge, the

specifications can be modified to leave all shrub cover regardless of height, as well as potentially low trees such as flowering dogwood (*Cornus florida* L.), gray birch (*Betula populifolia* Marsh.) and juneberry (*Amelanchier* spp.). These borders also provide wildlife and stability benefits. The resultant overall aspect is that of a valley—the forest edge giving way to shrubs and low trees and eventually lower shrubs and scattered herbaceous cover in the center. One recommended approach used to ascertain this pattern is the basal spray technique which involves the application of the chemical to the root collar region of the undesirable trees. The trail can also be maintained in this manner or, if just cut, by stub spraying existing woody stems. Locally, certain communities may be encountered whose nature makes the selective technique impractical and a more general coverage type spray necessary. The ultimate pattern created from a multi-technique approach will fulfill the needs of the utility most economically from a long-range point of view, and at the same time furnish maximum stability from the standpoint of tree invasion and simultaneously result in high conservation values.

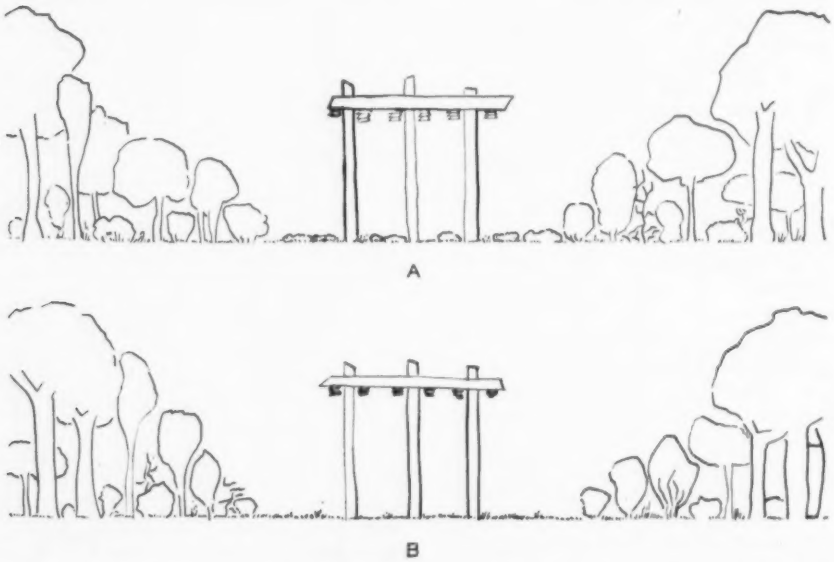

FIG. 1. Diagrammatic representations of two different vegetational patterns which can be created on right-of-ways by chemical manipulation.

A. Pattern recommended for highest general conservation values. Directly under the lines low shrubs and scattered grasses dominate. Beyond the outer wires taller shrubs and low understory trees create an edge effect which gives way to the upland forest.

B. Pattern recommended for maximum game values. Grasses and forbs dominate directly under the wires with the borders beyond the lines similar to the ones above.

(Illustration by Janet Smith.)

If the major interest is to create game habitat for such species as grouse, squirrel, woodcock, deer, cottontail and fox then the ultimate pattern prescribed would include more grasses and forbs,

especially if the surrounding vegetation is primarily forest (12). Here the area directly under the wires might be transformed to herbaceous cover by less selective techniques, leaving only the edges beyond the wires for shrubby and low tree species (Fig. 1 B). If desirable food plants are not present in this center strip it would be possible to establish "food patches". Although this technique provides optimum game habitat, the wide herbaceous strip tends to favor invasion by tree seedlings and root suckering species and thus these recommendations do not necessarily mean lowest maintenance costs for the utility on a long-range basis.

In summarizing, it is evident that both the utilities and the general public benefit from sound management practices when a predominantly selective approach is utilized. The utility benefits from better public relations as well as lower maintenance costs on a long-range basis since the vegetational pattern created aids in maintaining the lines. In addition, excellent wildlife habitat is established thus increasing the breeding area for upland game. Numerous other values previously mentioned would also accrue.

Problems and Progress

Why are sound ecological principles not being utilized on more of the nation's right-of-ways? To answer this question it is necessary to consider a more basic problem of which this is but a facet, i.e., the integration of our scientific knowledge into the national economy. Right-of-ways are merely one of many such commercial problems which arise in our economic structure. Several facts must be understood before a solution can be realized. Obviously in dealing with commercial enterprises, one is immediately confronted with industrial profits versus that which will be of the greatest benefit to the nation. This will be an almost insurmountable obstacle until there is a change in philosophy concerning our invaluable natural resources. In this instance, should the manufacturers of the chemicals assume more responsibility in supplying the best possible information to the consumer, or is this the job of the scientist? The present idea conveyed to the consumer is that he is dealing with "brush" which is undesirable, rather than dynamic plant communities which can and should be manipulated to both his advantage and the general good. Still another problem is that many utilities continue to entrust their management program to engineers regardless of lack of biological training. In the days of hand cutting when the vegetation was merely sheared to the ground with little change in composition this was satisfactory. However, with today's chemicals such radical destruction and modification results that persons with biological training are needed, in order to manipulate these areas most advantageously for the agency involved, as well as the general public.

In the field of research numerous projects are underway. At Pennsylvania State University there is an extensive project evaluating various techniques and their relation to wildlife (1, 2, 3). In Pennsylvania the State Department of Forest and Waters permits only sound spraying practices on the easements crossing state forests (8, 10). At the Connecticut Arboretum a right-of-way is being manipulated in order to impartially analyze current techniques from the standpoint of creating a desirable plant cover under the lines with maximum stability and wildlife values (13, 14). It is anticipated that this demonstration area will eventually exhibit results which will be of value to all those interested in power easement maintenance. In eastern United States the Committee for Chemical Brush Control has research areas ranging from New England to as far south as Florida (6). In Connecticut, the State Board of Fish-

eries and Game is cooperating with several utilities in supplying specifications for creating good game habitat on the lines (Fig. 1 B). In addition action has been taken by the Connecticut Botanical Society in establishing a Right-of-Way Vegetation Committee which investigates the management policies of the power companies in the state, publishes releases to aid the utilities, and offers an advisory service upon request.

What is the role of the scientist in this aspect of applied ecology? Is it merely to supply the data and then hope that it will eventually be adopted? The difficulty in hoping is that once the original vegetation is indiscriminately sprayed and destroyed, the principles set forth in this paper are superfluous. The future destiny of this tremendous acreage is most uncertain. Perhaps as land owners and conservation-minded groups become more aware of the potential values of these right-of-ways their pressure may influence the agencies involved to adopt sound management policies.

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The Industrial Utilization of Yeasts[1]

Yeasts are of immense importance industrially to mankind. Their activities are the bases of several primary industries and contribute to the support of many others. Revenues obtained from the sale of alcoholic beverages produced by yeasts in the United States amount to over four billion dollars annually.

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Introduction

Yeasts are microscopic organisms, which in some respects may be considered to be intermediate between the bacteria and molds. Their place in the vegetable kingdom is indicated below.

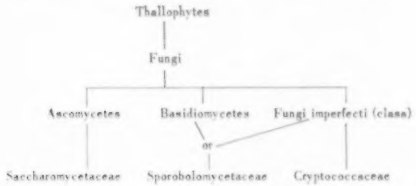

Fig. 1 illustrates industrial uses of yeasts.

Brewing

Brewing is concerned with the making of beer, ale, and other malt beverages.

The raw materials used in the manufacture of malt beverages in this country include malt, corn and corn products, rice, wheat, barley, sorghum grains, soybeans and soybean products, sugar and sirups, hops and hop extracts (Fig. 2). Usually 45 to 48 pounds of malt and malt adjuncts, including hops and hop extracts, are used for the making of one 31-gallon barrel of malt beverage.

[1] Contribution No. 344 from the Department of Food Technology, Massachusetts Institute of Technology, Cambridge 39, Mass.

Manufacturing Process. The malt, which is the source of the amylolytic and proteolytic enzymes, is ground, weighed, mixed with heated water in a mash tub, and agitated while the proteins are hydrolyzed (protein rest period of about one hour). The starch-containing malt adjuncts are ground (if necessary), weighed, mixed with water, and cooked with agitation in an insulated vat. This material is then added to the main malt mash. The *alpha* and *beta* amylases of the malt convert the solubilized starches to maltose and other products. The soluble portion of the mash (the wort) is separated from the spent grain residue by filtration and sparging in a Lauter tub. The wort flows to a brewing kettle where it is boiled in the presence of hops and hop extracts, which are added in two or more portions. Tannins, bitter resins, and essential oils are extracted from the hops during the boiling and contribute to the biological stability, bitterness, and flavor of the beer. The boiled wort is separated from the hop residues by straining, cooled to about 50° F., and pumped into fermentation tanks (open or closed) where it is inoculated with yeast (about one pound per barrel on a 75% moisture basis). The temperature at the beginning of fermentation is usually 45° to 60° F. The fermentation requires seven to eleven days

depending on the temperature. The fermented wort (green beer) is cooled and pumped to the storage tanks where it is held for two to six weeks at a temperature just above the freezing point for clarification and maturing. The beverage is chill-proofed with special proteolytic enzymes, carbonated, filtered with filter aids, and polished.

The finished product is metered and pumped to special areas in the plant for filling into barrels or into bottles or cans. The bottled and canned beverage is pasteurized at about 140° F. for 20 minutes. The containers are inspected, labelled, and packed into cases which are then stamped.

Reference to Fig. 3 will show that the amount of malt beverage manufactured is increasing from year to year but that the number of manufacturing premises is decreasing. Fig. 4 shows the leading states for malt beverage manufacture.

Yeast Utilization. The amount of yeast (special strains of *S. cerevisiae*) used for inoculating the wort varies from 0.6 to 1.4 pounds (75% moisture basis) per 31-gallon barrel with an average of about one pound per barrel. Since there were 90,697,911 barrels of beer and cereal beverage produced during the fiscal year ended June 30, 1956, this means that about 90,697,911 pounds of yeast were used. On a dry basis this would represent 22,674,478 pounds of dry yeast. Even on a somewhat more conservative basis, this represents a large amount of yeast.

During the fermentation an excess of yeast is produced, some of which is used to seed the next batch. Brewers' yeast, a by-product of this fermentation, is a

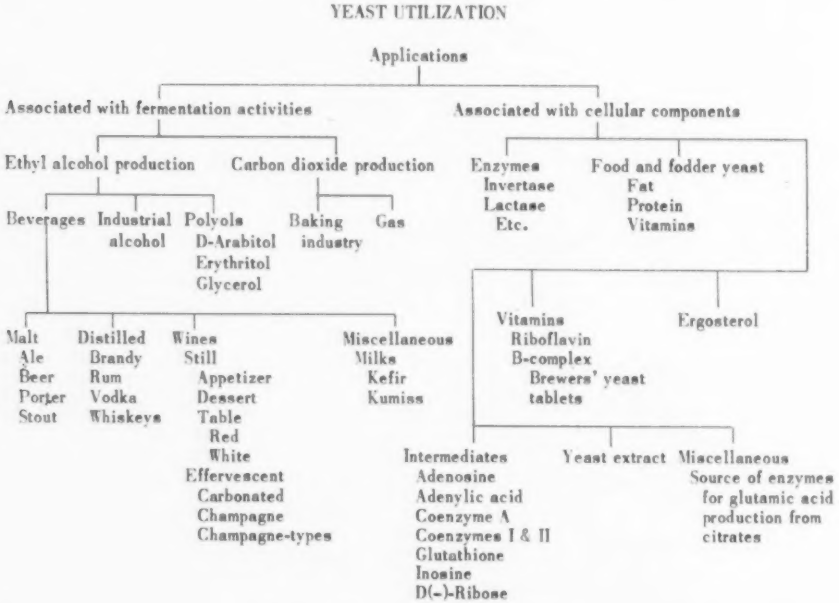

FIG. 1. Diagram of yeast utilization.

valuable item on account of its content of B vitamins and protein.

Wine-Making

Wine-making is a large industry in Europe, the United States, Africa, South America, and certain other parts of the world, where large quantities of yeast are used to produce alcohol from grape and other fruit sugars.

lated with two to five per cent by volume of pure culture of a wine yeast such as *Saccharomyces cerevisiae* var. *ellipsoideus*. Fermentation of the sugar takes place in the presence of the skins which impart desirable color to the wine. After this primary fermentation the wine is separated from the skins, pulp, and other deposits and placed in special wooden tanks for aging over a period of several

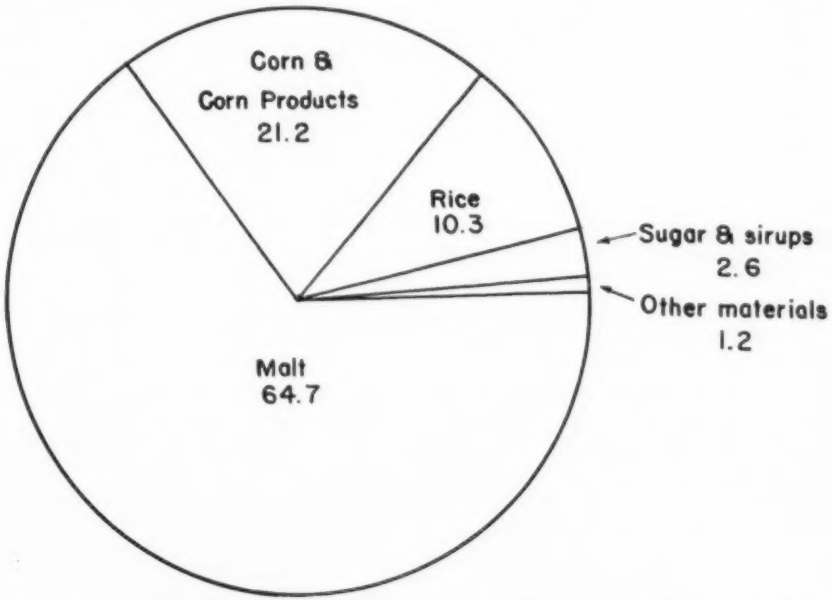

FIG. 2. Percentages of raw materials used for the manufacture of malt beverages in the United States during the fiscal year ended June 30, 1956. (Statistics from Publ. No. 67. U. S. Treas. Dept.)

The wines made in this country are classified as appetizer, table (red and white), dessert, and sparkling wines (7).

Methods used for making wines vary, depending in part on the class of wine being made. In the making of a red table wine special varieties of grapes are selected, harvested at the proper stage of maturity, crushed to liberate the juice, sulfited to inhibit the development of undesirable microorganisms, and inoculated with two to five per cent by volume of pure culture of a wine yeast such as *Saccharomyces cerevisiae* var. *ellipsoideus*. Fermentation of the sugar takes place in the presence of the skins which impart desirable color to the wine. After this primary fermentation the wine is separated from the skins, pulp, and other deposits and placed in special wooden tanks for aging over a period of several months to several years. Periodically the wine is racked. It is also refrigerated, pasteurized and filtered to separate out undesirable substances. Finally the wine is bottled and permitted to age in the bottles.

Data relating to the production of wines are shown in Fig. 5.

The federal excise taxes on wines for the year 1956 were in excess of $87,646,000, not including import duties (4).

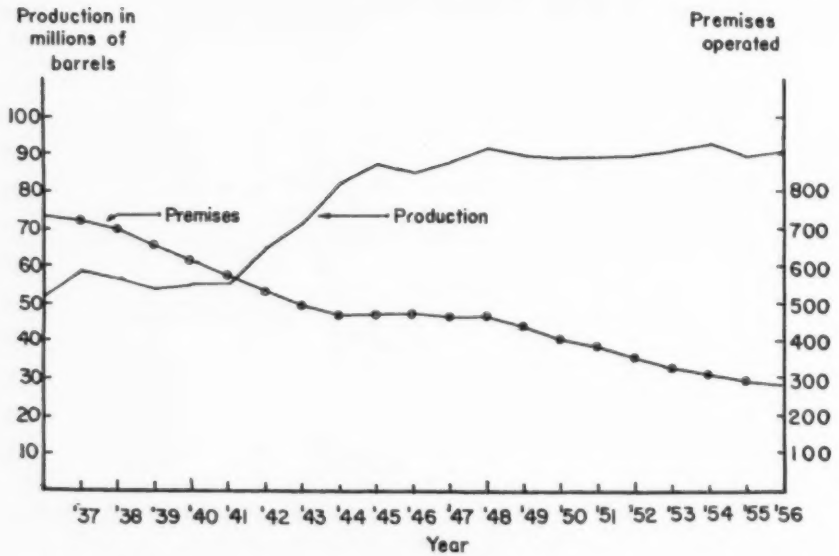

FIG. 3. Production of malt beverages and numbers of premises operated during the fiscal years (ended June 30) 1936 through 1956. (Statistics from reports of Comm. of Int. Rev. and Publ. No. 67. U. S. Treas. Dept.)

The Distilling Industries

Distilled spirits include whiskeys, brandy, rum, gin, vodka, and neutral spirits. Blended whiskeys, cordials and liqueurs, and compound gin are beverages prepared by blending or mixing.

Whiskeys

Whiskeys are the most important distilled beverages made in this country.

Raw Materials. The usual raw materials used in making whiskeys are corn (the principal one), rye (second in importance), wheat, barley malt, and rye malt. The relative proportions of these materials used depends on the nature of the whiskey. For example, straight corn whiskey is distilled from a fermented mash which contains not less than 80% of corn grain, and straight rye whiskey is distilled from a fermented mash which contains not less than 51% of rye grain (5).

Preparation. The grain is ground, weighed, mixed with water (24 gallons to each 56 pounds, for example), and cooked. Corn is usually cooked with continuous agitation under pressure; rye may be heated to a maximum of 160° F. in order to prevent the development of undesirable flavor in the distillate (27). After cooking, the mash is cooled to 140° to 144° F., saccharified with the use of eight to ten percent of malt at this temperature, and diluted to the desired concentration by the addition of stillage and/or water.

Fermentation. The mash is inoculated with approximately three percent by volume of a special strain of *S. cerevisiae*. Fermentation is carried out at a temperature of 82° to 86° F. (preferably) for three to four days.

Distillation and Rectification. Alcohol and other volatile materials are separated from the fermented mash by dis-

tillation at less than 190 proof. Most whiskey is distilled in continuous stills at a proof not exceeding 160. Pot stills may be used for heavy-bodied whiskeys (27).

Aging or Maturing. Whiskey is aged for a minimum of 24 months but usually for four to eight years or even longer. It is stored for aging in charred new oak, uncharred oak, or reused oak barrels, according to the type of whiskey (5). The charred new oak barrel is the usual container.

During the process of aging, or maturing, reactions take place between the constituents of the whiskey and the barrel and the components of the whiskey. Some of these changes are oxidative in nature. They are controlled to a certain extent not only by the temperature, relative humidity, and ventilation of the storage area, but also by the nature of the cooperage, the proof, the congeneries present, and other factors. During aging, particularly during the first six to twelve months of storage, the proof, to-

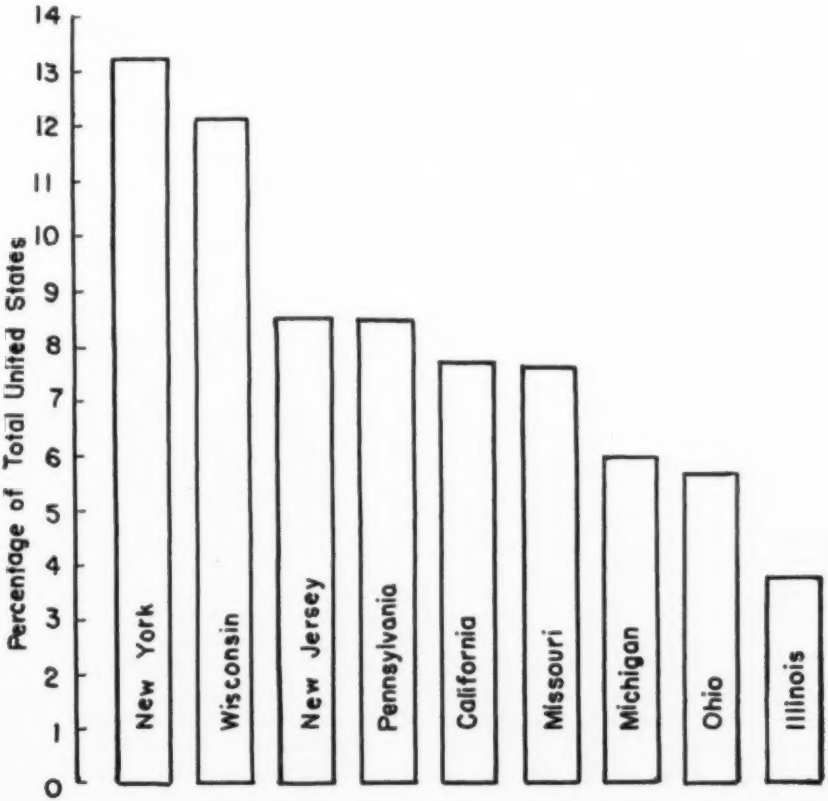

FIG. 4. Percentages of the total malt beverage production of the United States made by leading states during the fiscal year ended June 30, 1956. (Statistics from Publ. No. 67. U. S. Treas. Dept.)

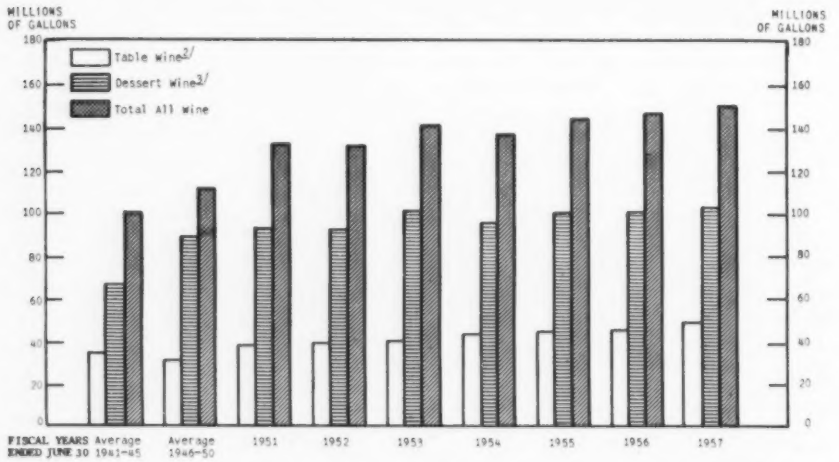

FIG. 5. Commercially produced wine entering distribution channels in the United States.[1] (Wine Institute Bull. 911, Dec. 1957, Wine Advisory Board.)

[1] Refer to Bull. No. 911 for special notes.

[2] Includes sparkling wine.

[3] Includes vermouth and other specially flavored natural grape wines.

tal acids, fixed acids, esters, aldehydes, furfural, fusel oil, solids, and color increase (27).

There were 118,796,431 tax gallons of whiskey produced in the United States during the fiscal year ended June 30, 1957 (6). The federal excise tax on this amount of beverage at $10.50 per proof gallon amounted to $1,247,000,000. This figure is exclusive of state, local, and other taxes. It is thus seen that yeasts, through their action in producing whiskey, are a source of very large revenue for this country.

Rum

Rum is the alcoholic distillate obtained from the fermented juice, sirup, molasses, or other by-products of sugarcane, distilled at less than 190 proof in such manner that it possesses the aroma, taste, and characteristics which are generally attributed to rum and includes mixtures of such distillates. New England rum is rum produced in the United States, distilled at less than 160 proof, and is "a straight rum and not a mixture of rums" (5).

Blackstrap molasses is the usual material for making rum. It is weighed and mixed with stillage (distillation slops) and/or water to provide a sugar concentration of about 12% in the mash. Deficiencies in nitrogen, phosphorus, or other elements are corrected and the pH is adjusted to about 4.5. The inoculum, a special strain of *S. cerevisiae*, is used in an amount representing three percent or more of the volume of the mash. The mash may be lightly aerated at the beginning to favor the development of the yeast. Fermentation is carried out preferably at a temperature not exceeding 86° F. until the sugar has been largely converted to alcohol and carbon dioxide. Occasionally, the fermented mash may be allowed to stand a short time before distillation to favor the development of bacteria, which tend to yield a heavier-bodied rum.

The fermented mash is distilled and rectified in a manner analogous to that of whiskey. The distillate is placed in charred new oak or reused oak barrels. When the latter are used, a small amount of charred oak chips are usually added to accelerate aging.

Aging is carried out in a bonded warehouse where the conditions are controlled as in the maturing of whiskeys. The types of changes which occur during the aging of rum are very much like those taking place in whiskey.

Rum is produced in Kentucky, Massachusetts, and Pennsylvania. There were 1,687,316 tax gallons of rum produced in the United States during the fiscal year ended June 30, 1957, which included 1,510,925 tax gallons removed for denaturation. There were 2,551,971 gallons of molasses used for the production of this amount of rum.

An excellent publication entitled "Studies on Rum" has been prepared by Rafael Arroyo (10).

Vodka

This distilled product may be prepared from grains, sugarcane products, or fruits.

Production from Pear Wastes. One concern in Oregon manufactures vodka from pear wastes in accordance with the following procedure described by Yang (52).

Cull pears, crushed in a hammer mill and pulper, and cannery pear trimmings (pulped at the cannery) are placed in a fermenter. The pulp, which contains six to ten percent of sugar, is inoculated with a special champagne-type strain of *S. cerevisiae*. Special nutrients, as required, are added to the mash. The temperature of the fermentation is kept below 85° F., and the fermentation is complete in 72 hours.

Distillation. The fermented product is preheated to 160° F. and fed into the central section of a column still. While at a low proof, the distillate is diverted through a fusel oil decanter where the fusel oil is removed. It is then returned to the still and emerges at the top at a proof of 190. The high-proof spirits enter the center section of a second still, where its direction is reversed. The "heads" (lighter congenerics, acids, esters, aldehydes) are removed from the top of the still and withdrawn. The low-congeneric spirits are conveyed from the bottom of the still through a cooler to singlings tanks.

Purification. The proof of the spirits is reduced to 110 with distilled water, pumped to processing tanks, and treated

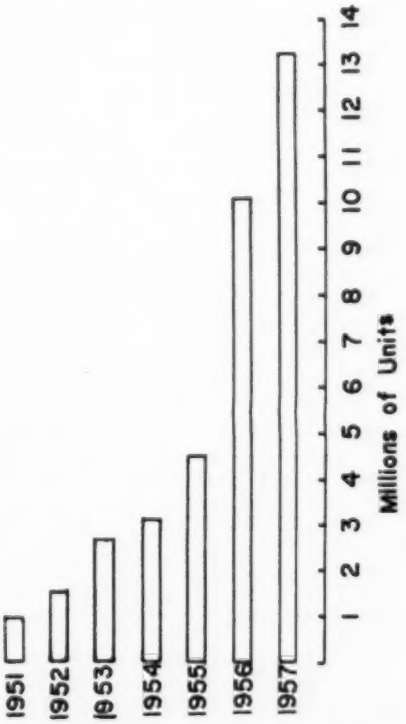

FIG. 6. Vodka bottled for consumption during the fiscal years (ended June 30) 1951 through 1957. The unit is a wine gallon. (Statistics from Publ. No. 67. U. S. Treas. Dept.)

with activated carbon (pharmaceutical grade) to remove the odor and flavor of pears. The mixture of spirits and activated carbon is agitated for several hours under lock and key. It is then filtered with diatomaceous earth or filter aid to remove the activated carbon. It is further purified and polished by additional filtrations.

Final Treatment. The vodka, thus prepared, is pumped into a bonded warehouse, gaged, and stored in glass-lined tanks. Prior to bottling, it is gaged again for tax purposes, reduced to 80 proof with distilled water, polished by final filtration, and bottled.

Statistics. The amount of vodka being produced in the United States is increasing annually. Connecticut, Illinois and Kansas were the three leading producing states during the fiscal year ended June 30, 1957.

Reference to Fig. 6 will show that the amount of vodka bottled for consumption has increased several fold since the fiscal year 1951.

Industrial Alcohol

Ethyl alcohol (industrial alcohol, ethanol) is produced by chemical and fermentation means.

Raw Materials. In view of the relatively high cost of blackstrap molasses and the low costs of ethyl sulfate and ethylene gas, increasing amounts of the latter substances are being used for the chemical synthesis of ethanol in the United States. Actually, 82.77% of the total ethyl alcohol produced during the fiscal year ended June 30, 1957, was made from ethyl sulfate and ethylene gas.

Raw materials used for fermentation alcohol during the fiscal year 1957 included molasses (which accounted for 8.96% of the total alcohol produced), corn, malt, wheat, sorghum grain, rye, sulfite liquors, pineapple juice, whey, fruit wine, enzyme extract, and other substances (6).

Celluloses and hemicelluloses, if used, must be converted to sugars by acid hydrolysis. Starches may be transformed into soluble products by malt enzymes, in which case the chief sugar is maltose, or by fungal amylases produced by submerged culture, by moldy bran, or by acid, in which cases the main sugar formed is glucose.

Conditions of Fermentation. During the production of ethanol by fermentation, the composition of the mash, the pH, and the temperature are controlled. The production medium generally contains 12 to 18% of fermentable sugars, although in some instances it may contain less; a suitable supply of nitrogen in the form of ammonia, ammonium sulfate, or diammonium hydrogen phosphate, or as organic material; phosphorus, as diammonium hydrogen phosphate, phosphoric acid or other compound; and magnesium. The actual requirements depend on the nature of the medium. Dilution of the molasses, if this is used as the raw material, is accomplished with water and stillage (distillation slops). Sufficient acid (sulfuric or lactic) may be added to adjust the pH to a desired point, such as 4.5. A special strain of distillers' yeast (*Saccharomyces cerevisiae*) possessing biochemical stability, high production capacity, and tolerance for ethanol is used as the inoculum in amounts representing 3 to 10% of the volume of the mash being seeded. The fermentation is carried out at the optimum temperature for ethanol accumulation, which is usually around 86° F. or somewhat below. During a period of two to three days the sugars are largely converted to ethanol and carbon dioxide.

Recovery and Treatment of Alcohol. The fermented mash ("beer") is distilled and refined. It may be sold as a

pure product or in denatured form (specially or completely denatured) (37).

Yield. A yield of 0.8 proof gallon may be expected from each gallon of blackstrap molasses.

Polyols

The polyols referred to herein include glycerol, D-arabitol and erythritol.

Glycerol. The production of glycerol industrially by fermentation has been carried out on a limited scale at times in the past.

The sulfite process was used on a large scale during World War I by the Germans. The basis for this process was the use of sodium sulfite to fix the acetaldehyde formed by the yeast (*S. cerevisiae*) from sugar, which resulted in the reduction of a triose intermediate to glycerol instead of the normal breakdown of sugar into approximately equimolar portions of ethanol and carbon dioxide (37). About one pound of yeast was used for each ten pounds of sugar contained in a mash. Yields of 20 to 25% of glycerol (based on the sugar) were usually obtained.

Glycerol was produced from molasses on an industrial scale in South Africa, using calcium sulfite in an alkaline fermentation (18).

General information on glycerol production by fermentation may be obtained by reference to "Industrial Microbiology" by Prescott and Dunn (37).

Production by Osmophilic Yeasts. Some yeasts, classified as osmophilic yeasts, are known to possess the ability to produce glycerol, D-arabitol and erythritol (44, 45, 46, 47). Representative of such yeasts are *Saccharomyces rouxii* and *S. mellis*. Factors influencing the production of these polyols by osmophilic yeasts have been studied by Spencer, Roxburgh and Sallans (45) and by Spencer and Shu (47).

One of the advantages of using osmophilic yeasts is that it is not necessary to add sulfites or alkalies to divert the normal course of the fermentation, thus reducing the cost of production and lessening the problem of recovery.

The production medium may contain glucose (20%), yeast extract or corn steep liquor, and urea. Temperatures of 77 to 98.6° F. may be used for fermentation, with best yields of glycerol being obtained at 98.6° F. Increased rates of aeration increase the yield of glycerol. As high as 0.60 g. of polyols (0.29 g. glycerol and 0.31 g. D-arabitol) was obtained under optimum conditions from 1 g. glucose (45).

Bakers' Yeast

Bakers' yeast is prepared from certain strains of *Saccharomyces cerevisiae*, which are selected on the basis of biochemical and physiological stability, gas-producing characteristics, keeping qualities, and other factors. It must be able to meet rigid specifications established by the using agencies (34).

Propagation. Bakers' yeast is propagated with careful control under strongly aerobic conditions in order to favor the development of cells to the exclusion of ethyl alcohol and other fermentation products.

The yeast is isolated in pure culture and propagated through a number of laboratory and plant stages. During propagation the composition of the medium, pH, aeration, foaming, temperature and other variables are carefully controlled.

Most bakers' yeast is manufactured by the molasses-ammonium process, although it may be prepared from saccharified grains, nutrient sugar solutions, or other raw materials.

Molasses-Ammonium Process. The materials used in this process are usually a mixture of cane and beet molasses, ammonium salts, and other essential nutrients not supplied by the molasses.

Molasses often contains substances,

such as sulfur dioxide or zinc salts, which are somewhat toxic. Likewise, it contains microorganisms. For these reasons molasses is usually treated by sterilization and clarification before use. Chemical agents may be used to help clarify the molasses. Clarification may be effected through the use of centrifuging, by filtration, or by settling followed by decantation. The treated molasses is diluted with water before being added to the propagation tank.

An adequate supply of suitable nitrogen sources is essential. Although some of the nitrogen is provided by the molasses, most of it is made available by the addition of various combinations of ammonia, ammonium sulfate, diammonium phosphate, or urea. Occasionally, small amounts of corn steep liquor or ammonium tartrate may be used. The amount of nitrogen used must be carefully controlled.

Phosphates are also important and may be supplied through the use of diammonium hydrogen phosphate, phosphoric acid, or calcium acid phosphate. It may be necessary to add a source of magnesium if the molasses is deficient in this element. Certain vitamins of the B-complex are required by *S. cerevisiae*. These are ordinarily supplied by a correct combination of cane and beet molasses (51).

The yeast used to inoculate the main propagator is built up through six or seven stages from a single cell to an inoculum containing several hundred pounds or more of cells. During the initial stages little or no aeration is supplied. However, during the last two or three stages of development, the starter is aerated.

The main propagation tank, after careful cleaning, may be partly filled with water. Some of the nutrient salts are added along with a small amount of the concentrated molasses wort. Aeration is provided. The yeast starter is added.

During the propagation a number of variables is controlled. The addition of molasses is accomplished exponentially at such a rate that the amount of sugar in the mash is only a fraction of a percent at all times. The mash is aerated vigorously, the rate increasing as the yield of yeast increases. The amount of air, supplied as small bubbles, may vary from 200 to 500, or more, cubic feet per pound of new yeast produced (on 30% solids basis), depending on the nature of the aeration (17). Foaming is controlled by the automatic or manual addition of a nontoxic chemical antifoam agent. The pH is kept within the range of four to five in some plants, although lower values are sometimes maintained. The temperature is preferably held under 86° F. for optimum results. Ammonia or other nutrients are added as required. The addition of nutrients is generally stopped about one hour before the end of the propagation period to allow the cells to mature. Aeration is greatly reduced during the final hour. The usual time of propagation is around twelve hours (2).

Final Operations. The yeast cells are separated from the spent production medium by the use of centrifugal separators. The yeast slurry thus obtained is mixed with water in a wash tank, and the yeast is again separated. This process is repeated until the yeast is free of extraneous matter. The yeast is next concentrated by passage through a filter press. The moisture content of the compressed yeast may be adjusted, and yeast plasticisers and improvers may be added. After blending the yeast is shaped, cut, wrapped, and stored just above the freezing point. It should be distributed and used as soon as possible after manufacture.

The federal specification for compressed yeast (8) states that it shall possess a "firm consistency and a smooth, springy texture", that it shall possess a

"light cream color", that the moisture content shall not exceed 73%, that it shall be "substantially free of wild yeasts and foreign organisms, and that the rope spore count shall not exceed 100 per gram".

Utilization of Bakers' Yeast. Large quantities of yeast are propagated for use in the baking industry, particularly for making bread, rolls, raised doughnuts, and crackers.

A rough estimation of the annual amount of bakers' yeast used in making bread in the United States may be made on the basis of an average daily consumption of 6 ounces of bread per individual for a population of 172,000,000 for 365 days and of the use of an average of two pounds of yeast for each 155 pounds of bread. This would amount to about 304,096,000 pounds of yeast.

Activated Dry Yeast

Activated dry yeast was developed to provide a product with better keeping qualities than compressed yeast, which could be used at long distances from the point of manufacture. Strains of *S. cerevisiae*, which are able to withstand dehydration satisfactorily, are used. The yeast is propagated in a manner similar to that for compressed yeast. It is extruded for drying purposes as a granular type or pellet type product. The granular product may be dried on a belt dryer in an atmosphere which is controlled in respect to air flow, humidity, and temperature. The pellet type product may be dried in a revolving tunnel dryer. Other forms of drying may be used. Drying must be accomplished in such a manner that the least possible amount of injury is done to the physiological state of the cell (21). The federal specification permits a moisture content not exceeding eight percent and a rope spore count not exceeding 100 per gram (8). The product should be stored at a temperature not exceeding 70° F. (30).

One pound of active dry yeast is used for each 100 pounds of flour in the straight dough method. The yeast is suspended in seven pounds of water at 110° F., mixed thoroughly, allowed to stand for five minutes, and then added to the other ingredients of the dough (30).

Food Yeast

Food yeast (or nutritional yeast) when made for feeding to animals is often called fodder yeast. Food yeast is manufactured and utilized on account of its nutritive values. Such yeast contains about 50% of protein on a dry basis ($N \times 6.25$), and it is also a good source of vitamins of the B-complex and certain minerals.

Species of Yeasts Utilized. A number of different species of yeasts have been and are being used industrially for producing food yeast. The most popular yeast for this purpose is *Candida utilis*, formerly known as *Torulopsis utilis* and often called torula yeast. Strains of this species are particularly desirable for use with sulfite liquors and wood sugar hydrolyzates because of their abilities to use certain carbon sources for growth purposes which are not used by *S. cerevisiae*. *C. utilis* is used for the industrial production of food and fodder yeast in this and several other countries. *S. cerevisiae* is a highly desirable yeast when blackstrap molasses is the raw material. Other yeasts which have been used on a laboratory or larger scale include *Candida arborea*, *C. pulcherrima*, *C. reukaufii*, *C. tropicalis*, *Hansenula anomala* and *H. suaveolens*.

Raw Materials. Theoretically and practically, a relatively large number of carbon sources may be used for the production of food yeast. Some of the more complex sources, such as celluloses, must be hydrolyzed by acid first. Sulfite liquors must be treated to remove excess sulfur dioxide. Sulfite liquors are the

primary source of food yeast in the United States and are important in a number of other countries for the same purpose. Blackstrap molasses, when sufficiently low in cost, is an excellent source of sugars. As in the manufacture of bakers' yeast, it is necessary to add certain nutrients to the mash to insure production of the highest yields.

FIG. 7. View of the top portion of a food yeast propagator. (Courtesy of Dr. R. T. Foote, Red Star Yeast and Products Co., Green Bay, Wisc.)

Process at Lake States Yeast Corp. Sulfite liquors from the pulp mill are screened and collected in large blend tanks (24). They are pumped, while hot, from the blend tanks to the top of a steam stripper where the sulfur dioxide content is reduced. The stripped material, which is at a low pH and which contains approximately 1.5% sugar (20% pentose), is passed through a cooler to the propagator, which is a modified Waldhof tank.

Since food yeast is produced by a continuous process, treated sulfite liquors are fed into the propagator continuously. Diammonium phosphate and potassium chloride in aqueous solution are supplied from a head tank, which in turn is supplied by a nutrient mixing tank. Ammonia, dissolved in water, is fed continuously into the propagator. The pH is maintained at about 5. Air is supplied through an aeration wheel which revolves at 300 r.p.m.

Yeast suspension is continuously removed from a location near the bottom of the propagator and passed through

line filters to a cone defoamer. Foam is transferred back to the propagator. The yeast is separated from the production medium by a centrifugal separator, washed three times, and conveyed to a refrigerated cream tank. The suspension of yeast is dried on drum dryers. The dried yeast is passed through a flaker to a cyclone mixer. It is bagged in 50- or 100-pound amounts.

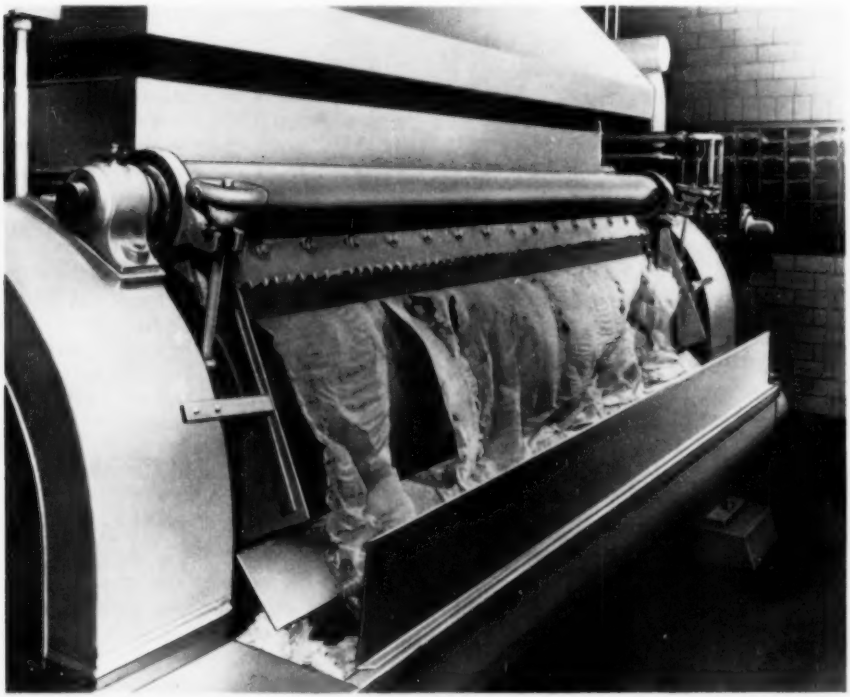

FIG. 8. Drum dryer in a food yeast plant. Dried food yeast is being removed in sheets from the dryer. (Courtesy of Dr. R. T. Foote, Red Star Yeast and Products Co., Green Bay, Wisc.)

Production at the Rhinelander, Wisconsin, plant of the Lakes States Yeast Corp. amounted to 1,900 tons in 1957, of which about 17.5% was used for human food end purposes (23).

Analysis. One analysis of torula yeast produced industrially from sulfite liquor showed the following, according to Inskeep, Wiley, Holderby and Hughes (24): 5.85% moisture, 9.07% ash, 1.92% phosphorus (as P), 0.85% calcium (as Ca), 47.43% crude protein ($N \times 6.25$), and 4.84% crude fat (obtained after prehydrolysis). Vitamin assays, in terms of gammas per gram, indicated 5.3 thiamine, 45.0 riboflavin, 33.4 pyridoxine hydrochloride, 37.2 pantothenic acid, 2.3 biotin, 417.3 niacin and 21.5 folic acid. Yeast protein is somewhat low in sulfur-containing amino acids, but this deficiency may be corrected by adding an adequate amount of methionine to the diet. Additional data on the nutritive value of food yeast may be obtained by

reference to the reports of Carter et al. (15), Dunn (20), Prescott and Dunn (37) and others.

Production. It is difficult to determine the amount of food yeast produced on a world-wide basis, but it is believed to be quite large. It has been reported that 40 metric tons of yeast are produced daily in Formosa from molasses (11).

Brewers' Yeast

Brewers' yeast is a valuable by-product of the brewing industry. It is used for food purposes, since it is a good source of vitamins of the B-complex, proteins and certain minerals. Brewers' yeast intended for human consumption is washed to eliminate the flavor of hops. Large amounts of brewers' yeast have been used in food products, such as dried soups. It is the source of brewers' yeast tablets.

Fat Yeast

Fat yeast is yeast produced for its fat content. During World War I the Germans produced fat yeast industrially from *Trichosporon pullulans*, then known as *Endomyces vernalis*. Unfortunately, this yeast has not been propagated successfully by submerged culture methods.

One of the best producers of fat is *Rhodotorula glutinis* (*R. gracilis*). This yeast is capable of producing over 50% of fat on a dry basis under optimum conditions. In the cultivation of *R. glutinis* by submerged culture methods it is necessary to use a medium deficient in nitrogen. The propagation of fat yeast is not likely to be important in the United States, but it may become so when acute shortages of fat are imminent.

Yeast Extracts

Yeast extracts are water-soluble products prepared from yeast by one of several methods: (1) autolysis, (2) acid hydrolysis, and (3) plasmolysis. These methods have been described briefly by Pyke (39). The preparation of yeast extract from brewers' yeast by autolysis has been described by Maizel (29) and others.

Yeast extracts are used in the food industries, in the pharmaceutical industry, and as a constituent of bacteriological and fermentation media. Their uses have been reviewed by Somogyi (43).

In the food industries yeast extracts may be used in soup mixes, meat fillers, gravies, stews, meat loaves, potted meats, luncheon meats, canned liver, and other foods (29). The extract may also be used as a food after the addition of vegetable extracts for flavoring purposes.

Yeast extract, made by autolysis, is distributed by a number of media supply concerns. It is widely used in media in concentrations of 0.3 to 0.5% to supply vitamins of the B-complex, nitrogen and minerals. Uses in the fermentation industry have been discussed by Prescott and Dunn (37), Underkofler and Hickey (50) and others.

Riboflavin

Riboflavin, vitamin B_2 or G, is produced by a large number of microorganisms in relatively small amounts. Yeast-like microbes, such as *Eremothecium ashbyii* and *Ashbya gossypii;* yeasts, such as *Candida flareri, C. guilliermondia,* and *C. arborea;* and bacteria, such as *Clostridium butyricum,* possess the ability to produce this vitamin in amounts which are industrially practicable.

The raw materials used for riboflavin production by yeasts and yeast-like microorganisms are, for the most part, readily available and relatively inexpensive. A comparatively large number of carbon and nitrogen sources may be used. These have been reviewed by Pridham (38), Prescott and Dunn (37), Beesch and Shull (12, 13), and others.

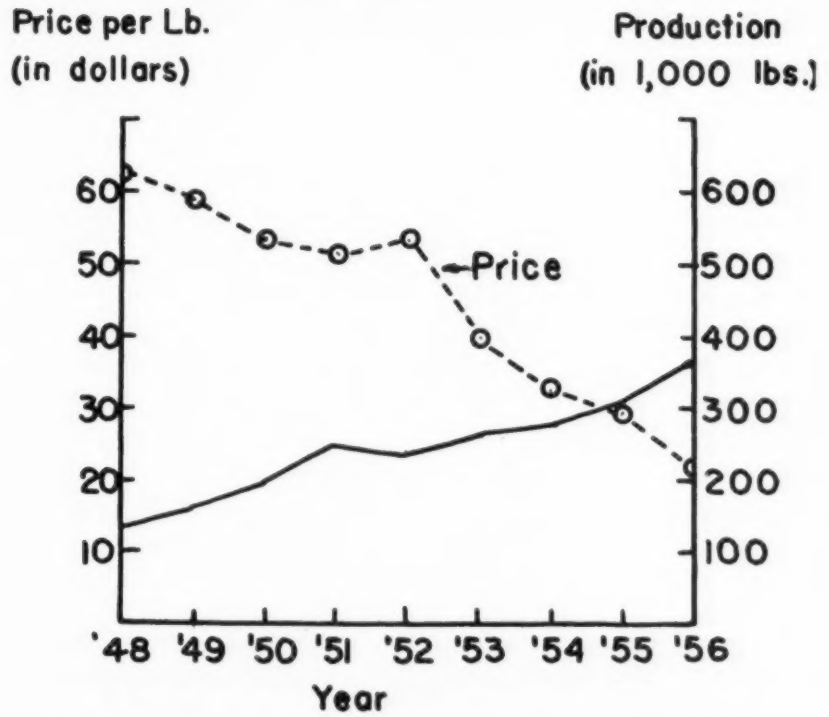

FIG. 9. Price per pound and production of riboflavin in the United States for human, animal and poultry uses during the years 1948 through 1956. (Statistics from Reports of the U. S. Tariff Comm., Synthetic Organic Chemicals. U. S. Govt. Printing Office. Washington, D. C.)

Production by *Ashbya gossypii*. The principal patents relating to the production of riboflavin by *A. gossypii* have been assigned to the U. S. Department of Agriculture and are thus free for use by citizens of the United States.

Pfeifer et al. (35) used 2.0% glucose, 1.8 to 2.1% corn steep liquor, and 1% animal stick liquor as the chief raw materials for riboflavin production with *A. gossypii*. The mash was sterilized at a temperature of 275° F. for five minutes at a pH of 4.5 and adjusted to 6.5 with sodium hydroxide before use. Fermentation was carried out at 83° to 85° F. for four to five days with aeration (0.25 vol./vol. medium/min.) and agitation. Yields of 500 to 848 μg./ml. were obtained. Dried concentrates may contain 25,000 to 30,000 μg./g. (38). Much higher yields may be obtained; for example, by adding glucose to the production medium after the fermentation has reached a given stage, it is possible to obtain yields of up to 1760 μg./ml. The addition of propionic acid may increase the yield.

Production by *Eremothecium ashbyii*. Riboflavin is produced by *E. ashbyii* by submerged culture methods which are similar to those used for *A. gossypii*. The production medium, in addition to a vitamin source, may contain a protein source with a carbohydrate and/or lipid.

Fish meal, meat scraps, peptone, dried blood, and other materials may be used as protein sources; and the common hexoses and disaccharides, and glycerol, and/or corn, coconut, cod liver, or other oils or lipids, as carbon sources (38). Yields may be enhanced by the addition of adenine, xanthine (28), L-threonine, L-serine, L-tyrosine, pyruvic acid, succinic acid, and certain other substances. Yields of up to 2,480 μg./ml. have been reported for this microbe.

Production by *Candida* Species. Production of riboflavin by species of the genus *Candida* has not, in general, been as spectacular as that with the yeast-like fungi. However, fairly good yields of the vitamin may be obtained by cultivating the yeasts in synthetic or semi-synthetic media in which the ion content (particularly iron) is carefully controlled. Yields of as much as 567 μg./ml. have been obtained by Levine et al. (26).

Statistics. The overall production of riboflavin is shown in Fig. 9. It will be noted that the production rate is increasing from year to year and that the price per pound of the vitamin is decreasing.

Information is not available to indicate the amounts of riboflavin produced by the different microorganisms. However, a large proportion of the microbiologically-produced riboflavin in this country is made by *Ashbya gossypii*. Approximately 75% of all the riboflavin is made by the use of microorganisms.

Ergosterol

Ergosterol is an important sterol produced by a fairly large number of species of fungi, lichens, and yeasts (14).

Ergosterol production by yeasts has been studied by Dulaney et al. (19). They observed that the ergosterol content of all of the genera of yeasts studied by them, except *Saccharomyces*, was less than 0.1% of the dry weight of the cells, which was regarded as being extremely low. They found that the highest yields of ergosterol were obtained from *S. cerevisiae*, *S. carlsbergensis* and *S. oviformis* in the genus *Saccharomyces*. Ale yeasts appeared to be the best of all yeasts for producing ergosterol. Yields of three to four grams of ergosterol were obtainable under optimum conditions from a liter of production medium. The ergosterol content of some of the best strains of *S. cerevisiae* ranged from seven to ten percent (on a dry yeast basis).

Appleton et al. (9) confirmed the superiority of species of the genus *Saccharomyces* as a source of ergosterol. They found average sterol contents of 1.02 to 2.90% in the dry cells of *S. cerevisiae*.

Ergosterol is used for the preparation of vitamin D_2 by ultraviolet irradiation.

In view of the present great interest in steroids, especially their microbiological transformation, the utilization of ergosterol as a starting material has received new attention.

Biochemical Intermediates

A number of compounds, classified as biochemical intermediates, may be isolated from yeast. These are of particular value for research purposes; some are used in the field of medicine. This subject has been reviewed rather briefly by Laufer, Schwarz and Stewart (25), and Pyke (39).

Glutathione. This compound is γ-glutamylcysteinylglycine. It may be recovered from yeast by direct extraction according to the method of Pirie (36), Schroeder and associates (40), or others (16). It occurs in amounts ranging from 100 to 300 mg.% in pressed yeast (25).

Glutathione is of interest physiologically, pharmacologically, and in the field of medicine. It has been shown to possess some protective action against irradiation when administered before this occurs. It is capable of reversing induced diabetes in rats and diabetes produced by ACTH in human beings (25).

Coenzyme I. Diphosphopyridine nucleotide (DPN) is known as coenzyme I, or cozymase. It may be obtained from yeast by direct extraction.

Coenzyme II. Triphosphopyridine nucleotide (TPN) is known as coenzyme II. It is obtained by direct extraction of yeast and is closely related to coenzyme I; that is, it possesses an additional phosphate group.

Ribonucleic Acid. This substance, known also as yeast nucleic acid, or RNA, may be prepared by the extraction of dried yeast (25) in yields of up to five percent or more. A number of compounds may be prepared from yeast ribonucleic acid, as is shown in Table 1.

TABLE 1

DATA CONCERNING SOME COMPOUNDS WHICH MAY BE PREPARED FROM YEAST RIBONUCLEIC ACID

Chemical compound	Empirical formula	Synonym
Adenine	$C_5H_5N_5$	6-Aminopurine
Adenosine	$C_{10}H_{13}O_4N_5$	Adenine riboside, nucleoside or ribonucleoside
Adenylic acid	$C_{10}H_{14}O_7N_5P$	Adenine nucleotide or ribonucleotide, or adenosine monophosphate
Cytidylic acid	$C_9H_{14}O_7N_3P$	Cytidine nucleotide or phosphate, cytosine ribonucleotide, or cytosylic acid
Guanine	$C_5H_5ON_5$	2-Amino-6-hydroxypurine
Guanosine	$C_{10}H_{13}O_5N_5$	Guanine riboside or nucleoside
Hypoxanthine	$C_5H_4ON_4$	6-Oxypurine
D-Ribose	$C_5H_{10}O_5$	
Xanthine	$C_5H_4O_2N_4$	2,6-Dihydroxypurine

Trehalose. This sugar is a disaccharide which yields two molecules of glucose upon hydrolysis. It may be obtained by the extraction of bakers' or brewers' yeast.

Adenosine Triphosphate. This compound, a vasodilator useful in the experimental treatment of certain diseases such as rheumatoid arthritis, may be prepared by the yeast phosphorylation of adenosine.

Other Compounds. Compounds, such as adenosine 5′-monophosphate, adenosine 5′-diphosphate, and fructose-1,6-diphosphate, may also be obtained by yeast phosphorylation reactions.

Inosine may be prepared from adenosine.

Yeast Enzymes

The yeast cell is a source of a comparatively large number of enzymes and coenzymes (37). Two yeast enzymes, invertase and lactase, are manufactured for use in the food industry.

Invertase. Yeast, especially *Saccharomyces cerevisiae*, is one of the best sources of invertase, which is found also in some bacteria, molds, higher plants, and other sources.

Invertase is used to produce invert sugar in the food industry, it is important in the fermentation industry, and it may be used for analytical or preparative purposes.

Neuberg and Roberts (33) have discussed the production, recovery, and applications of invertase.

Lactase. This enzyme is produced by *Saccharomyces fragilis*, *S. lactis*, special strains of *Candida pseudotropicalis*, and other yeasts (32, 53).

Lactase catalyzes the conversion of lactose to one molecule each of galactose and glucose. One of its principal uses is

to prevent the crystallization of lactose, with attendant graininess, when this sugar is present in relatively high concentration in dairy mixes.

Miscellaneous Applications

Saccharomyces cerevisiae ATCC 9763 is used as a test organism in the cylinder-plate method for assaying the antibiotics, anisomycin and nystatin (22).

Saccharomyces cerevisiae, S. fragilis, Candida utilis, Torulopsis cremoris, and certain other yeasts may be used in a patented method for preparing L-glutamic acid in an aqueous solution containing citrate and ammonium ions (42).

About three pounds of dried, debittered, brewers' yeast may be mixed with 97 pounds of grated American cheese to enhance and stabilize the cheese flavor (49).

Yeast has been, and may be, used for the removal of glucose from egg white by fermentation; however, the use of a glucose oxidase is now the favored procedure.

Lactose-fermenting yeasts are used in the preparation of kefir and kumiss, alcoholic beverages made from milk.

Phenylacetylcarbinol may be produced by yeast from glucose or pyruvic acid and benzaldehyde. The mechanism of the formation of this compound from pyruvic acid and benzaldehyde has been studied by Smith and Hendlin (41). They found that cocarboxylase, Mg^{++}, dephosphopyridine nucleotide, and coenzyme A were necessary as coenzymes.

Selected species of yeast are used for fermenting the sugar of fruit juices to ethyl alcohol in the making of vinegar. Acetic acid bacteria convert the alcohol to acetic acid.

Yeasts are used in the making of soy sauce.

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Utilization of Citrus By-Products[1]

Proceeds from the production of by-products may spell the difference between profit and loss in the citrus canning industry. The three primary by-products of citrus are dried citrus pulp, molasses, and citrus peel oil. The most important utilization of citrus wastes is as stock feed, which consumes large quantities of dried pulp and citrus molasses. Citrus seed oil, alcohol, pectin, bland syrup, and feed yeast have been produced to a lesser extent.

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Introduction

Since the 1920–30 decade the processing of citrus fruits has grown rapidly to be a vast and important part of the Florida citrus economy. The industry has grown to such proportions in recent years, particularly since the development of frozen citrus juice concentrate in 1945, that 60 to 70 percent of the Florida orange and approximately 50 percent of the Florida grapefruit crop is now processed, as seen in Table 1.

Since over half the fruit is peel, pulp, and seed (Table 2), a whole new industry was born out of necessity to solve a most difficult waste disposal problem. In the 1949–50 season, when a total of 48 million boxes of oranges and grape-

[1] Florida Agricultural Experiment Station Journal Series, No. 727.

TABLE 1

NUMBER OF BOXES AND PERCENT OF FLORIDA ORANGES AND GRAPEFRUIT UTILIZED IN PROCESSING CHANNELS (45)

Season	Oranges processed		Grapefruit processed	
	1,000 boxes	Percent	1,000 boxes	Percent
1947–48	30,421	52	19,451	59
1949–50	34,707	59	13,489	55
1951–52	47,507	60	13,678	38
1953–54	62,904	69	20,089	48
1955–56	64,884	71	18,658	49

TABLE 2

PHYSICAL AND CHEMICAL COMPOSITION OF GRAPEFRUIT AND ORANGES (37, 39, 42, 51)

Physical		Chemical	
Component	Percent	Component	Percent
Juice	40–45	Water	86–92
Flavedo (outer peel)	8–10	Sugars	5–8
Albedo (inner peel)	15–30	Pectin	1–2
Rag and pulp	20–30	Glucoside	0.1–1.5
Seeds	0–4	Pentosans	0.8–1.2
		Acids (citric mostly)	0.7–1.5
		Fiber	0.6–0.9
		Protein	0.6–0.8
		Fat	0.2–0.5
		Essential oil	0.2–0.5
		Minerals (K, Mg, Ca, P, etc.)	0.5–0.9

fruit were processed, two million tons of refuse remained for disposal by the citrus by-product industry. Today processing by-products is an essential part of the citrus industry and is also important to other industries. The rapidly growing Florida cattle industry utilizes large tonnages of two primary by-products, dried citrus pulp and citrus molasses, as stock feeds.

The manufacture of the various by-products is best visualized by consulting Fig. 1, which shows schematically the handling of citrus fruits from the time they are picked. The canning plant receives oranges, grapefruit, and tangerines both from the field and from the packinghouse. Packinghouse fruit usually includes the larger and smaller sizes not generally shipped, as well as other sizes having surface blemishes. All fruit passes over grading belts where split and bruised fruits are rejected. The peel, rag, and seeds from the juice extractors and finisher, combined with these rejected fruits, are the source of the by-products of citrus. Dried citrus pulp, molasses, and citrus peel oil are the three primary by-products. However, citrus seed oil, alcohol, pectin, bland syrup, and feed yeast have been produced to a lesser extent.

The production of citrus by-products is now firmly established as an integral part of almost every citrus canning plant, and in some years the proceeds from by-products could spell the difference between profit and loss to the processors.

Citrus Pulp and Molasses

Dried citrus pulp and citrus molasses are discussed together at this point because the processing procedure in the early stages is identical and both products can be manufactured in a balanced operation.

The profitable utilization of citrus fruit residue for the past 25 years has resulted mainly from the production of dried citrus pulp. Approximately two million tons of this pulp have been produced in Florida alone since its value as a feed was first shown. Many investigators (4, 5, 9, 10, 26, 29, 35, 41) have shown it to be an excellent bulky carbohydrate feed for both beef and dairy cattle, with dried grapefruit peel having the further advantage of containing factors which stimulate milk production in dairy cows (3, 11).

Since the 1941–42 canning season, when citrus molasses was first produced, the production of this product has expanded to a large extent. It has proved to be an excellent carbohydrate concentrate, which not only is a feed in itself but also is used successfully to ensile non-saccharin grasses, to pelletize dried citrus pulp, and to increase the carbohydrate content of dried citrus pulp and mixed feeds (5). Recently a citrus molasses fortified with urea and containing an equivalent of 10 to 15 percent crude protein has been made available for stock feeding.

General Processing Procedure. The production of dried citrus pulp and molasses commences with the accumulated citrus cannery residue consisting of peel, rag, and seeds which represent approximately 50 percent of the whole fruit. Large tonnages of these residues, accumulated and held in unprotected open bins, are passed continually to hammer mills or shredders, where the peel is cut by rotating hammers or knives into pieces approximately ¼ by ¾ inch. About 0.15 to 0.3 percent hydrated lime is added as a powder or slurry immediately before, during, or after comminution of the peel. A rotating screw conveyor both mixes and conveys the limed pulp to a pug mill or curing bin. Local alkalinity changes the color of the chopped peel to a rather bright yellow, then slowly to a greyish straw color as the lime reacts with the acidic components. Although experienced operators

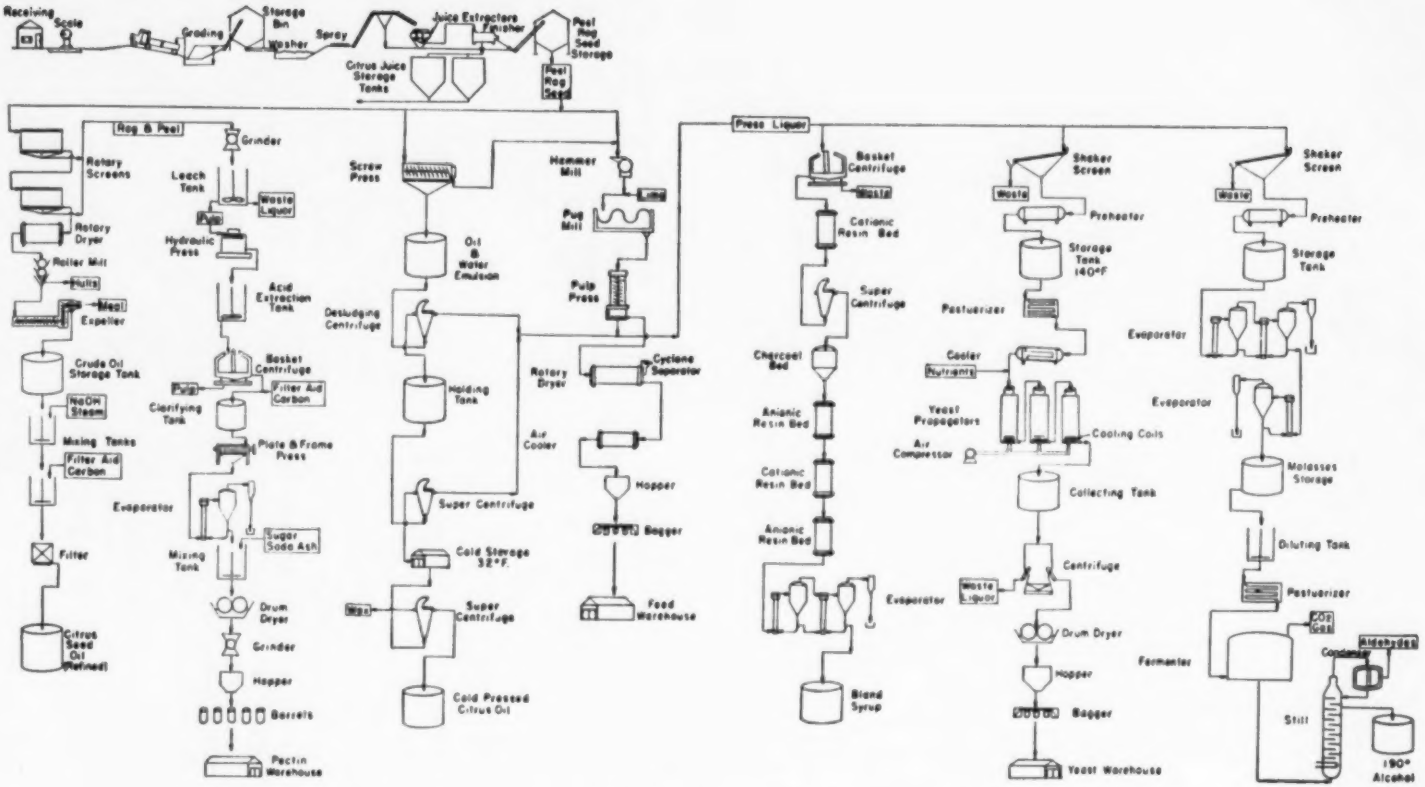

FIG. 1. A schematic diagram showing the overall manufacture of citrus by-products.

are able to judge the proper quantity of lime to add by feel and consistency of the peel, automatic control instruments have been used by industry. High local alkalinity resulting from the slow diffusion of lime is indirectly responsible for a rapid degrading and demethylating of pectins present. Precipitation and coagulation of the pectin with lime causes the cells to break down and the lime to permeate the peel thoroughly. The pH of the unbound liquor is then lowered, and at the same time syneresis sets in, facilitating removal of the press liquor. Processes using a pug mill, which might be described as a huge modified screw conveyor, allow approximately 15 to 25 minutes curing time prior to pressing. Those using large holding bins generally allow about half an hour for the lime to react. In the laboratory where the peel was chopped into smaller pieces, five minutes reaction time appeared sufficient, although longer time aided the expulsion of press liquor. After curing, the peel is carried by conveyor to continuous mechanical presses, such as the Davenport, Louisville or Zenith. All three types are used in Florida. These continuous mechanical presses squeeze the limed peel, reducing its moisture content from approximately 82 to 72 percent or lower, and about 60 percent of the weight of the original residue is obtained as press liquor. The flow diagram for this commercial process is shown in Fig. 2.

In Texas a somewhat different arrangement is employed (44). Curing bins of 10-ton capacity are filled with limed, chopped peel. As the bound water is released by the lime, it drains and is collected, reducing the moisture content of the peel from 83.0 to 81.8 percent. This process yields 20 percent press liquor on the weight of original residue without the aid of mechanical presses. The apparent high yields of press liquor obtained in this and the above example are mathematically explained by Pearson's rule (38), which takes into account the numerically close dry solids content of the press liquor versus the unpressed peel. At present, several processors in Florida are using a procedure that avoids pressing.

Citrus Pulp. The pressed residue, usually containing 65 to 82 percent moisture, is conveyed to rotating driers where it is dried to 6 or 8 percent moisture. The driers commonly used are the long cylindrical rotary drier and the triple pass rotary direct-fired drier. The dried pulp empties directly from the driers into cyclone type separators, in which the hot gases from the drier are whirled around the inside of a cone. The dried solids fall onto the wall of the cone while hot gases exhaust to the atmosphere. From the cone the dried pulp is conveyed to a cooler that usually consists of a rotating drum through which air is passed counter-current. Open screw conveyors also have been used for cooling. The dried pulp at this point is divided into three products: the counter-current cooling air carries off the fines or dust; a rotary screen on the lower end of the cooling drum separates the portion called citrus meal; and the material carried through is the dried citrus pulp. The citrus meal is considered to be of lower quality and is generally sold at a reduced price, while the fines or dust are even less valuable and are sold usually as a fertilizer conditioner. For this reason processors have taken considerable care to operate their plants in such fashion as to avoid fines and meal. A few processors consider it more advantageous to burn fines as heating fuel than to bag and sell them. A typical plant will produce approximately 91 percent dried citrus pulp, 8 percent citrus meal and 1 percent fines.

According to Heid (19), many of the disadvantages attributed to oil-fired rotary driers, such as excessive kiln

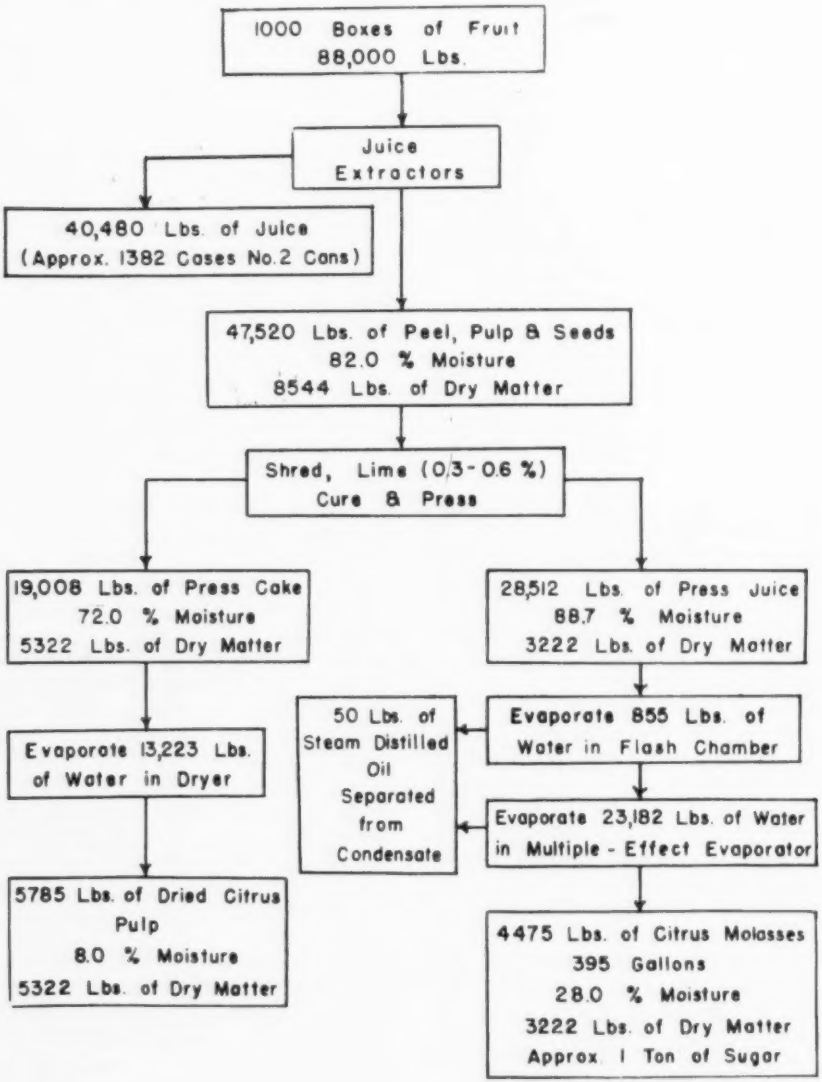

FIG. 2. Flow and material balance sheet for the processing of citrus residues into dried pulp and molasses.

temperatures, burning of fines, lower yield, and the fire hazard due to sparks, can be eliminated by multiple stage drying. In this operation three kilns maintained at 230° F. dry the pulp to 32 percent moisture, and drying is completed in a fourth kiln at a gas discharge temperature of 180° F. A steam-tube rotary drier is used advantageously as the fourth drier, since it allows closer temperature control, but it is generally more expensive because a boiler is necessary. Exhaust steam from a cannery, if available, may be used economically at this stage. Two-stage drying is also done in Texas (44), using three identical parallel-flow rotary kilns held at 255° F. in the first stage. Final drying, completed at 200° F., reduces the moisture content from 40 to less than 10 percent. When pressing is not practiced, as in Texas, sticking sometimes occurs in the drier because the feed is too wet. However, if the feed is too dry, it may be scorched. There is at present considerable debate as to the most economical drying procedure for producing a quality product that is bulky and which results in a minimum of fines.

Many processors make a sugar-sweet pulp, adding 20 to 30 percent citrus molasses to this pulp before, during, or after the drying operation. Sometimes more molasses is added, depending on the marketing area to which the pulp will be shipped. Dried citrus pulp is slightly hygroscopic, and, if proper care is not taken, the product will increase in moisture content to the point where it will mold and heat while in storage, thereby lowering the quality of the feed. If the feed is permitted to heat excessively, it can become a definite fire hazard due to spontaneous combustion.

Table 3 presents the average feed analysis of dried citrus pulp calculated from numerous published (3, 9, 25, 30, 35, 40) and unpublished analyses. Since the product is made by a number of methods and from a mixture of orange and grapefruit, there is some variation from sample to sample. The addition of citrus molasses increases the carbohydrate content and decreases the fiber content.

TABLE 3

TYPICAL FEED ANALYSIS OF DRIED CITRUS PULP

Component	Percent
Crude protein	6.2
Fat	3.5
Crude fiber	13.0
Nitrogen-free extract	63.0
Ash	4.3
Dry matter	92.0

Citrus Molasses. Limed peel when pressed yields a press liquor, peel juice, or press juice, whatever it may be called, that contains 8 to 15 percent total dissolved solids, of which more than half are sugars. It has a pH ranging from 5.5 to 7.0. The press liquor passes through a stainless steel shaker screen to eliminate grosser particles and then is sent to a large holding tank. It is processed quickly through heat exchangers that raise the temperature to approximately 240° F.; then it is flashed to atmospheric conditions. This operation serves four purposes: (1) peel oil is distilled off and recovered as an additional by-product; (2) the high temperature kills all spoilage organisms; (3) calcium citrate and other calcium organic salts with inverted solubilities are precipitated; and (4) the flocculation of other suspended matter is aided. Considerable scale is deposited in the high temperature exchanger. However, this is considered advantageous, since it substantially decreases scale deposit later in the multiple-effect evaporator and permits longer periods of operation between shutdowns. Some processors partially clarify the liquor before it enters the evaporator by settling out suspended matter in the hot press liquor storage tank. The

hot press liquor is concentrated to 50° Brix in a multiple-effect evaporator and usually is screened to eliminate the larger scale particles that may have loosened in the evaporator. A forced circulation finishing pan completes concentration to 72° to 75° Brix. A schematic flow diagram for a four-body, triple-effect evaporator is shown in Fig. 3.

In Texas (44) the abundance of natural gas allows the use of an Ozark submerged burner. The unit is fed a balanced mixture of air and gas to effect initial concentration of the press liquor by submerged combustion. The press liquor then is allowed to settle and is concentrated further by the same type burner prior to going to the multiple-effect evaporators. These burners bring about a natural carbonation that lowers the pH to 6.0.

Citrus molasses is required to meet minimum state standards. It must contain 45 percent total sugars, expressed as invert sugar, and test not less than 33.5° Brix by double dilution. A typical analysis compiled from published (20, 21, 30) and unpublished data is shown in Table 4.

TABLE 4

TYPICAL ANALYSIS OF FLORIDA CITRUS MOLASSES

Brix°	72.0
Nitrogen-free extract	62.0
Total sugars %	45.0
Moisture %	29.0
Reducing sugars %	23.5
Sucrose %	20.5
pH	5.0
Carbonate ash %	4.7
Acid, as anhyd. citric %	4.5
Nitrogen % × 6.25	4.1
Glucoside %	3.0
Pentosans %	1.6
Pectin %	1.0
Fat %	0.2
Volatile acids %	0.04
Fiber %	0.00
Potassium (K) %	1.1
Calcium (Ca) %	0.8
Sodium (Na) %	0.3
Magnesium (Mg) %	0.1
Iron (Fe) %	0.08
Chlorine (Cl) %	0.07
Phosphorus (P) %	0.07
Silica (SiO_2) %	0.01
Manganese (Mn) %	0.008
Copper (Cu) %	0.003
Niacin (p.p.m.)	35
Riboflavin (p.p.m.)	11
Pantothenic acid (p.p.m.)	10
Inositol	..
Viscosity 25° C. centipoises	2000

TABLE 5

PHYSICAL AND CHEMICAL PROPERTIES OF 10 SAMPLES OF STRIPPER OIL

Stripper oil	Maximum	Minimum
Specific gravity 25° C./25° C.	0.8433	0.8398
Refractive index N_D^{20}	1.4721	1.4713
Optical rotation a_D^{25}	+98.90	+95.55
Aldehyde content %	1.50	0.47
Ester content %	2.46	0.07
Evaporation residue %	0.79	0.03

Citrus Stripper Oil. Stripper oil is obtained as a by-product from the manufacture of citrus molasses. Citrus press liquor contains 0.20 to 0.50 percent peel oil; and, since this oil steam distills readily, 60 to 80 percent of the oil present in the liquor can be recovered by flashing from 240° F. to atmospheric conditions. Florida has a potential stripper oil production of over one million pounds per year, based on the quantity of citrus molasses made in previous years. Not all processors are equipped to recover this oil; so yearly production is somewhat less. Stripper oil is usually a mixture of citrus oils, since the press liquor is obtained most often from a mixture of orange and grapefruit peel. It frequently possesses a fine citrus oil character, marred only by a slight distilled character, and contains very little of the waxy material ordinarily present in expressed citrus oils. Table 5 presents the physical and chemical properties of this oil.

Since stripper oil contains over 95 percent of D-limonene, it is considered one of the purest sources for this monocyclic terpene. Bell (6) recognized

this oil as an excellent high-purity, low-cost source material for making fine organic chemicals. A synthetic spearmint oil flavor, L-carvone, already has been manufactured from this oil. Considerable quantities of citrus stripper oil are bought yearly by the paint and varnish industry, since it is an excellent anti-skinning agent. Other uses for this oil are as an ingredient of clear plastics, as a base for soap perfumes, and as a penetrating oil.

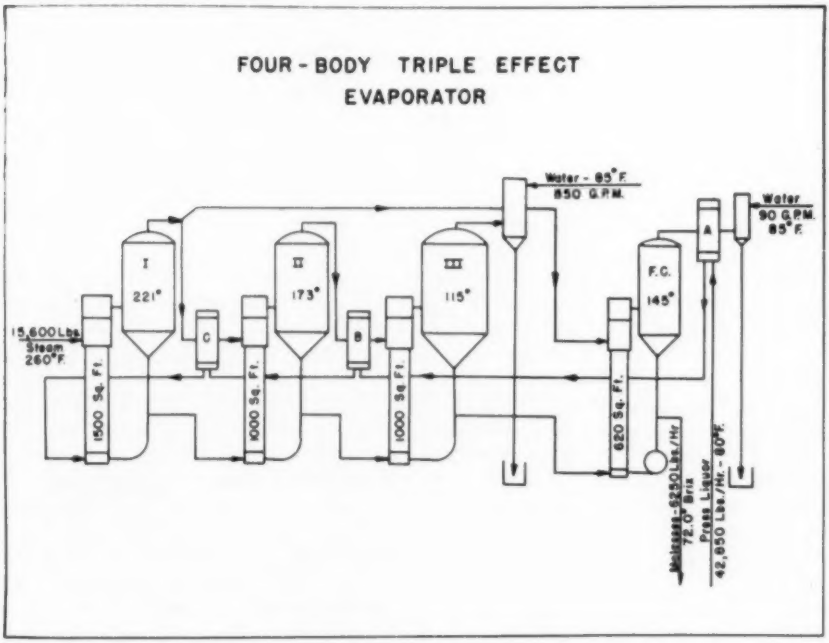

FIG. 3. Flow and material balance for a four-body triple-effect evaporator.

Citrus Peel Oil

The essential oil is the first product recovered from cannery refuse. Orange oil, the most useful citrus oil produced in Florida, commands a price which justifies the operation of a plant for its recovery.

Citrus oils are contained in oval, balloon-shaped oil sacs or vesicles located in the outer rind or flavedo of the fruit adjacent to the chromoplasts. Numerous oil sacs or glands are located irregularly at different depths in the flavedo of all citrus fruits. These glands or sac-like intercellular receptacles have no walls of the usual type but are bounded by the debris of degraded tissues. The cells surrounding the oil glands contain an aqueous solution of sugars, salts, and colloids and exert some pressure on the glands. Winton and Winton (51) and Braverman (7) describe the exact location of these oil sacs in their discussion of the structure of the flavedo of the orange.

To secure the oil from the peel of citrus fruits, oil sacs must be punctured by either pressure or rasping. Methods of oil extraction used in Florida were investigated by Kesterson and Hendrick-

son (24). Studies relative to the physical and chemical properties of Florida citrus oils are discussed in detail.

Coldpressed Oils. Citrus peel oils are expressed in Florida by three different types of equipment: (1) Pipkin roll, (2) screw press, and (3) Food Machinery Corporation In-Line juice extractor. A typical flow and material balance sheet for the screw press is shown in Fig. 4 to illustrate the recovery of peel oil. All of the above methods of extraction give an emulsion of oil and water. The oil is separated centrifugally from the aqueous phase by passing the emulsion through a sludger and then through a polisher. Following separation the oil is stored for approximately one week at 32° to 40° F. During this winterizing treatment undesirable waxy materials separate from the oil and settle. The clear oil is decanted into stainless steel storage tanks or tin-dipped containers, which are then maintained at a storage temperature of about 40° F. Air usually is excluded from the container to prevent deterioration, either by filling the container full of oil or by displacing the air with carbon dioxide.

Distilled Oils. Distilled oil of orange, grapefruit, or tangerine is secured by some processors as a by-product in the canning of citrus fruit juices. Some of the citrus peel oil becomes mixed with the juice as it is extracted in the canneries. Excessive amounts of peel oil in the juice are harmful to the quality of canned juice; therefore, in most canning plants the oil content of the juice is reduced to a desirable level by passing the juice through a de-oiler. The juice is usually flashed in the de-oiler, which is operated under a vacuum of 11 inches (190° F.) to 25.5 inches (130° F.), and a vapor mixture of oil and water is removed. The mixture of oil and water vapors is condensed, and the oil is separated from the condensate by decanting or centrifuging. Vacuum steam distilled oils manufactured in this manner will have properties slightly different from oils obtained by steam distillation at atmospheric pressure.

Typical Analyses for Coldpressed and Distilled Oils. Table 6 includes typical values for the physical and chemical characteristics of coldpressed and distilled orange, grapefruit, tangerine, and Persian lime oils produced in Florida. Also included in this table are results from the analysis of one sample of steam distilled oil from Meyer lemon. Properties of Meyer lemon oil indicate that it is predominantly lemon in character, although the Meyer lemon is commonly believed to be a natural hybrid.

Utilization of Citrus Peel Oil. In recent years the manufacture of orange oil, as well as of grapefruit and tangerine oil, has increased to a considerable extent in Florida. Essential oils, as they are called, find many and varied uses for the flavoring and scenting of various products. These oils are composed of mixtures of hydrocarbons, oxygenated compounds, and non-volatile residue. The hydrocarbons are primarily terpenes, while the oxygenated compounds are made up of a variety of compounds —aldehydes, esters, acids, alcohols, ketones, ethers, and phenols. Non-volatile residues consist of resins and waxes. The oxygenated compounds, the principal flavoring agents of citrus oils, may constitute from 1.5 to 6.5 percent of the original oil.

Because of their flavoring qualities, citrus oils have been used in a wide variety of products. Some of the industries in which they are employed are: perfume and toilet goods, beverages, extract, baked goods, canning, condiment, confectionery, food industry (general), ice cream, preserve, pharmaceutical, rectifying and alcoholic beverage, and soap.

Citrus Alcohol

Nolte and co-workers (37) demonstrated in 1942 that it would be eco-

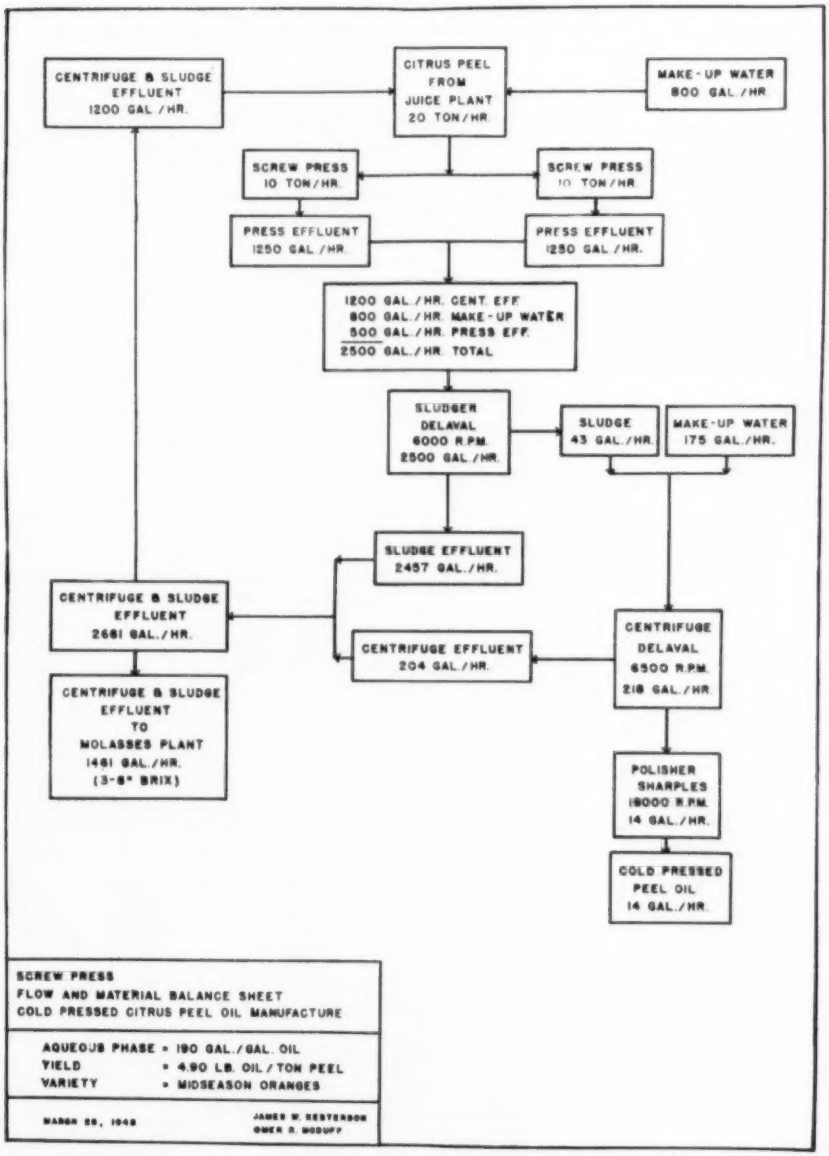
CENTRIFUGE & SLUDGE EFFLUENT 1200 GAL./HR.
CITRUS PEEL FROM JUICE PLANT 20 TON/HR.
MAKE-UP WATER 800 GAL./HR.
SCREW PRESS 10 TON/HR.
SCREW PRESS 10 TON/HR.
PRESS EFFLUENT 1250 GAL./HR.
PRESS EFFLUENT 1250 GAL./HR.
1200 GAL./HR. CENT. EFF.
800 GAL./HR. MAKE-UP WATER
500 GAL./HR. PRESS EFF.
2500 GAL./HR. TOTAL
SLUDGER DELAVAL 6000 R.P.M. 2500 GAL./HR.
SLUDGE 43 GAL./HR.
MAKE-UP WATER 175 GAL./HR.
SLUDGE EFFLUENT 2457 GAL./HR.
CENTRIFUGE & SLUDGE EFFLUENT 2681 GAL./HR.
CENTRIFUGE EFFLUENT 204 GAL./HR.
CENTRIFUGE DELAVAL 6500 R.P.M. 218 GAL./HR.
CENTRIFUGE & SLUDGE EFFLUENT TO MOLASSES PLANT 1461 GAL./HR. (3-6° BRIX)
POLISHER SHARPLES 18000 R.P.M. 14 GAL./HR.
COLD PRESSED PEEL OIL 14 GAL./HR.
SCREW PRESS
FLOW AND MATERIAL BALANCE SHEET
COLD PRESSED CITRUS PEEL OIL MANUFACTURE
AQUEOUS PHASE = 190 GAL./GAL. OIL
YIELD = 4.90 LB. OIL/TON PEEL
VARIETY = MIDSEASON ORANGES
MARCH 28, 1948
JAMES W. KESTERSON
OMER A. MOSUPP

FIG. 4. Flow and balance sheet for peel oil recovery using screw press.

TABLE 6

TYPICAL VALUES FOR THE PHYSICAL AND CHEMICAL PROPERTIES OF CITRUS OILS PRODUCED IN FLORIDA

	Type of oil							
	Orange				Grapefruit			
	Coldpressed		Distilled		Coldpressed		Distilled	
Number of samples analyzed	35		9		6		9	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Specific gravity 25° C./25° C.	0.8458	0.8416	0.8464	0.8400	0.8532	0.8508	0.8539	0.8415
Refractive index N_D^{20}	1.4734	1.4718	1.4732	1.4715	1.4761	1.4746	1.4746	1.4714
Refractive index of 10% distillate N_D^{20}	1.4715	1.4703	...	...	1.4712	1.4698	...	...
Difference	0.0031	0.0008	...	...	0.0054	0.0038	...	...
Optical rotation α_D^{25}	+97.76	+95.16	+98.56	+95.92	+92.96	+91.19	+96.50	+91.50
Optical rotation of 10% distillate α_D^{25}	+98.70	+96.81	...	...	+98.14	+95.81	...	...
Difference	2.44	0.00	...	...	6.33	3.68	...	...
Aldehyde content—%	2.04	0.92	2.48	1.72	1.67	1.49	4.06	2.30
Ester content—%	1.63	0.04	1.38	0.22	4.20	2.11	2.52	0.08
Evaporation residue—%	4.93	1.07	1.24	0.08	8.02	6.02	3.66	0.19

	Type of oil						
	Tangerine		Persian lime				Meyer lemon
	Coldpressed	Distilled	Coldpressed		Distilled		Distilled
Number of samples analyzed	1	1	6		5		1
			Maximum	Minimum	Maximum	Minimum	
Specific gravity 25° C./25° C.	0.8456	0.8407	0.8823	0.8798	0.8579	0.8556	0.8555
Refractive index N_D^{20}	1.4734	1.4720	1.4853	1.4842	1.4751	1.4743	1.4740
Refractive index of 10% distillate N_D^{20}	1.4711	...	1.4731	1.4729	...	...	...
Difference	0.0023	...	0.0123	0.0112	...	...	...
Optical rotation α_D^{25}	+91.18	+93.67	+41.80	+38.60	+50.52	+46.84	+56.00
Optical rotation of 10% distillate α_D^{25}	+92.68	...	+49.24	+47.60	...	...	...
Difference	1.50	...	9.88	7.00	...	...	...
Aldehyde content—%	1.08	1.24	5.52	3.66	2.71	1.61	1.19
Ester content—%	0.34	0.25	8.20	7.42	3.49	2.41	2.45
Evaporation residue—%	4.53	0.20	14.67	12.95	1.23	0.18	0.16

nomical to produce alcohol from citrus waste. However, it was not until cane molasses was in short supply and the demand increased for raw materials to produce ethyl alcohol during World War II that citrus was utilized for this purpose. During this period the one plant which produces alcohol from citrus molasses was constructed in Florida.

Citrus molasses is well suited for the production of alcohol (C_2H_5OH), since it contains carbohydrates in a form which permits direct fermentation by yeast.

General Processing Procedure. The manufacture of alcohol from citrus molasses consists of: (1) weighing and mixing, (2) preparation of the pure yeast culture, (3) addition of pure yeast culture, (4) fermentation, and (5) distillation.

Utilization of Citrus Alcohol. Ethyl alcohol made from citrus is, of course, identical with that made from such products as grain and cane molasses and can be put to similar uses. Whether alcohol made from citrus can compete with that from other sources depends on various economic factors.

Citrus Feed Yeast

Although citrus press liquor normally is concentrated to citrus molasses, it can be used advantageously also in the production of feed yeast. Yeast has considerable value as a feed supplement, since it is one of the richest natural sources of the B vitamins and contains about 50 percent protein. Nolte and co-workers (37) were among the first to investigate the possibility of fermenting citrus press liquor to feed yeast and alcohol. *Torula utilis*, a wild, fast-growing yeast, was selected because it propagated rapidly and produced little alcohol. This organism further appeared to give the best yeast yield of the five tested. Since the press liquor contained insufficient nitrogen and phosphates for optimum growth, it was necessary to add nutrient salts. From a liquor containing one percent total sugars, the workers obtained yields ranging from 44 to 48 percent dry yeast by batch operation, based on the total sugar content of the press liquor. Diluted press liquor containing not more than one percent total sugars produced higher yeast yields and faster propagation.

Veldhuis and Gordon (49) later were able to adapt to citrus liquors a continuous method of fermentation developed originally for the utilization and disposal of liquors obtained during the manufacture of starch from sweet potatoes. A schematic diagram of the continuous processing procedure (49) which gives the most successful results is shown in Fig. 1.

General Processing Procedure. Citrus press liquor from the continuous presses of a feed mill is first passed through an 80-mesh shaker screen to remove the larger particles. The suspended insolubles remaining are not considered objectionable in the final feed yeast. A preheater raises the press liquor temperature to 140° F. to prevent its premature fermentation while held in a large storage tank. The liquor is pumped from the storage tank through a pasteurizer operating at 200° F. and then cooled to approximately room temperature in a heat exchanger prior to entering the yeast propagators. A concentrated nutrient solution of ammonium sulfate and trisodium phosphate is fed continuously to the yeast propagator in proportion to the feed rate of press liquor. Other necessary nutrients are supplied by citrus press liquor. For most favorable yeast growth a pH between 4 and 5 must be maintained by the addition of either the nutrient solution or ammonia. Since the fermentation generates considerable heat, cooling coils are put in the bottom of the yeast propagator to maintain a constant temperature of approximately 96° F. Porous aeration tubes fitted in

the bottom of the propagator supply a continuous flow of air to maintain rapid yeast growth. The air inhibits fermentation and increases respiration, agitates the medium, removes toxic end products, and stimulates vegetative growth. From 500 to 1,200 cubic feet of air is necessary to produce a pound of yeast. The citrus press liquor moves continuously through the propagator so that in a single-stage plant the total detention time is only about three hours. The propagator discharges a yeast suspension to a collecting tank, after which a continuous centrifuge concentrates the yeast to a thick slurry of about 10 to 15 percent solids. This slurry is then dried by either a drum or spray drier.

Significant quantities of thiamin, riboflavin, ergosterol, niacin, and pantothenic acid also are present in the yeast.

No citrus processor at present is making feed yeast, since the economics seem to favor diversion of press liquor for production of citrus molasses. However, the process possibly could be used advantageously in the disposal of the more dilute waste liquors found in a citrus cannery because liquors of low sugar content can be utilized effectively.

Although feed yeast has achieved importance as a high protein feed for animals, it can be refined and made more palatable for human consumption. Since it is the richest natural source of biologically complete proteins and a rich source of a pellagra-preventing factor, it has many beneficial medical uses. In Germany during World Wars I and II it was recognized as an excellent source of essential nutrients and was used extensively in the preparation of "ersatz" foods.

TABLE 7

COMPOSITION OF DRY YEAST AND ANALYSIS OF ASH

Dry yeast	Percent	Ash	Percent
Moisture	1.29	Phosphorus pentoxide	45.75
Protein (N × 6.25)	55.28	Magnesium oxide	4.95
Crude fat	4.51	Calcium oxide	1.26
Glycogen	12.78	Silicon dioxide	2.58
Cellulose, gum, etc.	18.06	Sulfur trioxide	7.79
Ash	8.08	Chlorine	0.22
		Iron oxide	0.40
		Sodium and potassium oxides	37.05

Utilization and Composition. The spent liquor from the continuous centrifuges is discharged as a waste product. By this time the biological oxygen demand has been reduced 80 percent. Ninety-five percent of the sugars and about 65 percent of the total organic matter have been utilized. Veldhuis and Gordon (49) obtained 60-percent yields when press liquor was diluted with two volumes of water and 33-percent yields with full strength press liquor. This is equivalent to 20 to 36 pounds of feed yeast per 1,000 pounds of 10° Brix press liquor processed. The average composition of feed yeast from press liquor (Table 7) was compiled by Nolte and coworkers (37), who analyzed a composite of 10 samples.

Citrus Seed Oil

The production of citrus seed oil has grown steadily from 45 tons during the 1938–39 season (36) to an estimated yearly production of 500 tons. Although the manufacture of citrus seed oil has been of minor importance in the citrus industry, it seems to be a well-established small enterprise at present. The production of citrus seed oil seems to be highly desirable, since it provides a

more profitable outlet for the seeds than does processing into dried citrus pulp. Obviously, only seedy varieties of citrus are suitable.

According to Fudge (15), average yield of wet seeds from seedy varieties of grapefruit is about 2 to 2.5 percent of the weight of the whole fruit. Since the quantity (45) of seedy grapefruit processed in Florida during the 1949–50 season amounted to approximately 9.5 million boxes (85 pounds fruit per box), the potential yield of wet seeds would be about 9,000 tons. From this quantity of seeds a calculated yield of 1,350 tons of oil could be produced. Calculated yields are premised on the basis that wet seeds contain 50 percent moisture and dried seeds contain 30 percent oil. During this same period (45), 20 million boxes (90 pounds fruit per box) of midseason oranges, containing about 4 percent seeds on a whole-fruit basis, were processed. The potential yield of wet seeds would then be about 36,000 tons, and from this quantity a calculated yield of 5,400 tons of oil could be produced. The total potential of seed oil would be about 6,750 tons. Because only a few of the seeds available are utilized, the quantity of oil produced is considerably less.

At present there is one plant in Florida which specializes solely in the production of oil from citrus seeds. However, many processing plants collect and dry seeds and then ship them to an extraction plant for removal of the oil. Many investigators (1, 12, 13, 14, 22, 23, 27, 36, 47, 48) have determined the physical and chemical properties of these oils, showing their possible commercial use.

General Processing Procedure. The seeds are obtained usually from two sources: (1) residue from single strength and concentrate juice plants, consisting of peel, seed, rag, and pulp, and (2) the residue from sectionizing plants, which consists of only seed, rag, and pulp. A schematic diagram of the processing procedure for the manufacture of citrus seed oil is shown in Fig. 1. None of the common distillation methods has been found suitable for recovering or refining citrus seed oil.

Refining. Unrefined oil collected in holding tanks has a reddish color, a pleasant aroma, and an extremely bitter taste. The oil is refined by mixing it with a calculated amount of caustic soda solution. This forms an emulsion which breaks when the mixture is heated gently to 50° C. for 10 to 15 minutes with mild agitation. The precipitated soap stock is allowed to settle; then it is separated by filtration. The oil then is washed and heated to 100° C. to remove the last traces of moisture. The caustic treatment neutralizes free fatty acids and removes bitterness. The oil may be further refined by adding activated carbon and filter cel and filtering.

Utilization of Citrus Seed Oils, Meal, and Hulls. The flavor of a highly refined citrus seed oil resembles that of olive oil, for which it has been substituted. It is pale yellow in color and is considered wholesome and well suited for food. It has been used after hydrogenation in the manufacture of butter substitutes and, in some instances, a cooking fat. The lower grades of citrus seed oil are used in the manufacture of soap and in the preparation of sulfonated oils for the textile industry.

A brominated seed oil of high density (approximately 1.30) has been produced for use in the beverage industry. The density of the flavoring oils is adjusted to that of the drink by adding brominated oil, thus preventing ring formation around the top of the bottled beverage.

The press cake or seed meal usually is broken up and blended with dried citrus pulp and sold as cattle feed. The meal is high in protein and fat, both of which are essential in the diets of animals. Glasscock et al. (16) demonstrated that

citrus seed meal was as valuable as cottonseed meal in meeting the protein requirements of growing and fattening steers but that it was harmful to swine when fed at levels as low as 10 percent of the total ration. The meal has been used to some extent as a poultry feed. However, before it can be fed to poultry, it must be solvent-extracted to remove limonin, the bitter principle present in the seed (14).

The hulls are usually sold to fertilizer plants as a conditioner for fertilizer.

Citrus Bland Syrup

Each year approximately 20 million pounds of sugar are purchased by the citrus industry of Florida to sweeten single-strength citrus juices and canned grapefruit sections. Of this quantity, over half is used as a 40° to 50° Brix syrup in packing sections. At present this syrup is made by dissolving in a blending tank mixtures of sucrose and dextrose in water. A similarly sweet syrup can be made from citrus waste liquors by methods that may show economical advantages over the purchase of raw sugar. Since the sugars found in citrus are always partially inverted, there seems to be very little chance of making a crystallized sugar. However, liquid sugar solutions are easier to handle and are more in demand today. The production of bland syrup is premised on the use of ion exchange resins that have the capacity of removing, by exchange adsorption, the citric acid, minerals, and other impurities present in citrus juices. The dilute pure sugar solution thus obtained is then concentrated by conventional methods to the desired Brix.

The application of ion exchange resins has been investigated more thoroughly for demineralizing cane syrups, beet syrups, and molasses to increase yields of raw sugar. However, three citrus processing plants in Florida have, at various times, investigated ion exchange resins in pilot plant or moderate-scale plant equipment. Since the process requires considerable technical skill, as well as a large initial investment, its development has been slow. By persistent effort, one plant has applied the process to advantage.

In manufacturing citrus bland syrup, citrus press liquor should not be considered as the only source material for its production. Juice from excess citrus fruit, not suitable for production of concentrates or single-strength juice, could be used. Since citrus juices have a higher sugar purity and fewer impurities than peel liquor, their use can considerably shorten and simplify the process. Over-mature tangerines are especially suited, since tangerine juice tends to be very sweet and has a minimum of citric acid. With orange and grapefruit juices and orange and grapefruit peel press liquor the problem becomes successively more difficult. This is accounted for by two factors. Citrus fruits contain a bitter glucoside: hesperidin in the case of oranges and tangerines, and naringin in grapefruit, which is both bitter and difficult to remove. The bitterness of naringin is quite pronounced and apparently is more difficult to remove than that attributable to hesperidin. The quantity of glucosides is much higher in peel press liquors than in the citrus juice, due to the lime addition which increases the glucoside solubility. Gore (17) treated strained orange juice with five percent of an anion exchange resin and produced, after filtering and concentrating, a clear, well-flavored and well-colored syrup. Similarly prepared syrup from grapefruit juice possessed a bitter taste.

General Processing Procedure. Since the manufacture of bland syrup from citrus press liquor is most difficult, it has been described with the knowledge that certain steps can be avoided by using

juices of higher purity. The process is broken down conveniently into the operations shown in Fig. 1: clarification (20), ion exchange purification, decolorization (8), and concentration.

Citrus Pectin

The pectic substances in citrus peel are believed to be associated intimately with cellulose, either in the outer cell walls (46) or between each of the adjacent cellulose walls of the cells. Citrus peel is a rich source of pectin, the amount varying with season and variety. It is usually most abundant in immature fruit as protopectin, which can be liberated as soluble pectin by various enzymatic and chemical methods. As the season progresses, the jelly units of pectin in the peel diminish, and the quantity of insoluble protopectin decreases.

Since pectin is not a pure substance, its evaluation depends largely on the molecular size of the pectic substance, degree of esterification, amount of accompanying ballast material, and method of manufacture. The gelling power and viscosity of pectin solutions depend on the number of galacturonic acid units strung together to form each molecule, for the larger the molecular size, the higher the jelly strength. The degree of polymerization is dependent upon the extraction method. It is common to speak of pectin as having a certain grade, which refers to the number of pounds of sugar that can be gelled by one pound of the pectin in accordance with a standard method. Another term used conveniently is the jelly unit, obtained by multiplying together the percent yield and jelly grade of the pectin.

Although all citrus peels contain comparatively large quantities of pectin, lemon and grapefruit are most suitable for its extraction. In Florida, the production of pectin has been limited mostly to dried citrus pomace, a crude product bought by jam and jelly manufacturers, from which pectin is extracted by means of hot acid solutions. Approximately half the pectin manufactured in the United States is derived from citrus (mostly lemons). The production of a refined high grade pectin involves considerable know-how and experience, as well as a large capital investment. For these reasons pectin production in Florida has developed slowly.

General Processing Procedure. Methods of isolating pectin from citrus fruits are numerous. However, its manufacture can be broken down into four operations: leaching, extraction, clarification, and isolation.

Leaching. The accumulated canning residue, consisting of peel, rag, and seeds, is the raw material. This must be processed without undue delay, to inactivate (by heat) the enzymes present and thereby prevent the degradation of the pectin. The enzymes, protopectinase, pectinase, and pectase, are catalysts which cause the breakdown of pectin and seriously decrease the jelly units obtained. The seeds and rags are removed by passing the cannery residue through a rotary screen with one-inch openings. Fine water jets located inside the screen aid this separation. The peel is conveyed to a temporary storage point and withdrawn as required for leaching. Just prior to entering the leach tank the peel is cut into pieces from $\frac{1}{8}$ to $\frac{1}{4}$ inch in size. A weighed quantity of chopped peel is dropped from an overhead hopper into a false bottom leach tank fitted with an agitator and containing boiling water. The mass is agitated continuously to aid the leaching. Live steam is admitted to raise and maintain the temperature at 90° C. for five minutes. An equal quantity of cold water is added to reduce the temperature quickly from 90° C. to 60° C. Then the tank is drained immediately. Two further leachings of short duration are made with cold water. They remove most of the remaining sol-

uble constituents, such as sugars, acids, and minerals, which are considered contaminants. Some soluble pectin also is removed by this operation, but the loss is of little significance since it is of low grade. A hydraulic press squeezes the leached peel, releasing further traces of soluble impurities. The leached and pressed peel is now ready for extraction; or if desired, it may be dried in steam-tube rotary driers and stored in silos for subsequent use. Low temperature controlled drying is necessary to prevent excessive loss of grade. This dried product, containing five to ten percent pectin, is commonly called pectin pomace and has been used for the manufacture of jams and marmalades.

Extraction. The leached and pressed peel is conveyed into a tank fitted with a steam coil and agitator where the insoluble protopectin is converted to soluble pectin by acid hydrolysis. Conversion is carried out at a pH of approximately 2.4 over a one-hour period at approximately 90° C. The mass is agitated continuously during the extraction. Either hydrochloric or lactic acid can be used, but the entire operation must be controlled carefully since destructive hydrolytic action on the pectin itself is possible.

Extraction can be carried out with other acids also, both mineral and organic. Although the fundamental extraction conditions are not necessarily the same for all varieties of citrus fruit, Myers and Baker (33, 34) were able to determine the optimum pH, temperature, and holding time of lemon albedo for both maximum yield and maximum jelly units. One process, patented by Myers and Rouse (31), avoids the use of acid by adding a cationic exchange resin that adsorbs sufficient cations from the extraction solution to lower the pH to the proper extent. Although the exchange resin must be recovered later, this process has the advantage of decreased ash, simplification of isolation procedure, higher yields of high grade pectin at higher pH readings, removal of toxic heavy metals, lower viscosity at higher concentrations, and lower chemical costs. As the pectin dissolves in the acid solution, it becomes more and more viscous. Sufficient water, therefore, is added to the extraction tank to provide a relatively dilute pectin solution (0.5 to 0.7 percent). This dilution further aids in dissolving the higher grade pectin, which is increasingly insoluble. After one hour at 90° C. the contents of the extraction tank are cooled quickly to 60° C. by circulating cold water through the steam coils and the solution is then ready for clarification.

Clarification. The dilute viscous pectin solution and insoluble pulp are pumped to a basket centrifuge where much of the pulp is removed. The centrifuge effluent is collected in a clarifying tank and processed in accordance with its ultimate use. When manufacturing low methoxyl pectin, it is convenient to de-esterify the pectin solution at this point. Three methods are generally available for partially demethylating pectin: (1) acid hydrolysis wherein the pH is decreased by adding hydrochloric acid, (2) enzyme hydrolysis by pectase of tomato origin, and (3) mild saponification with ammonia at much reduced temperatures. Since the last two methods are rapid, they are used commercially. However, care must be taken to inactivate or neutralize the enzyme before the reaction proceeds too far. Further purification and decoloring is accomplished by stirring the pectin solution with activated carbon for 20 to 30 minutes at 55° to 60° C. After a small quantity of filter aid is added, the pectin solution is filtered through a precoated plate and frame filter press and is ready for isolation.

Isolation. The isolation of pectin from its solution can be accomplished by

numerous methods, but it is advantageous first to concentrate the clear dilute pectin solution in multiple-effect evaporators under reduced pressure. The pectin solution is concentrated as much as its viscosity will conveniently allow and sent to a blending tank where the pH is adjusted to 3.5 with ammonia or soda ash, depending on ash specifications. Sugar is added to standardize the grade, whereupon the 4 to 6.5 percent pectin solution can either be sterilized and sold as a liquid or dried by a rotary drum or spray drier.

Another process, requiring considerably more skill, depends on precipitating the pectin at an adjusted pH with an aluminum salt and ammonium hydroxide, skimming, pressing and vacuum-drying the product. It is refined further by washing with acid alcohol and then plain alcohol to remove the last trace of acid and aluminum. The product is vacuum dried again. Dried pectin can be obtained as either a flake or a powder, depending on the drying technique used. However, the dried product usually is micropulverized and marketed as a very fine powder.

Utilization of Citrus Pectin. Jellies, jams, and marmalades in their various forms are probably the first products which utilized pectin. However, it was not recognized until some 25 years ago that pectin alone was not sufficient for the manufacture of gels. It has since been found that the presence of pectin, sugar, and acid in the proper proportions is necessary for the manufacture of jelly products. Today the preserve industry is still the largest single outlet for this substance. Continued research has developed new applications for pectin, considerably increasing its use.

Confectionery. The shortage of critical supplies in the candy industry (18) has resulted in a stimulated research program to develop new products in order to maintain volume production. Among these products are modified pectins obtained by partial de-esterification, referred to as low-methoxyl pectins. This type pectin is used to produce low-sugar-content candies as well as to develop new types of candies. Low-methoxyl pectins depend upon a reaction with a metallic ion such as calcium to form gels, rather than an acid and a high concentration of sugar. The pectins have been used to make jellies, pectin jelly candies, and cream-center-type candies. They also have been used to form protective coatings or glazing agents for candies.

Meat Packing. Pectinate films (43) used in the meat packing industry, such as casings on sausages, ham, and other processed meats, are applied by dip coating. The process is simple; the meat is molded into the desired shape and then dipped in a dispersion of calcium sodium pectinate. The gel coating is dried, and the resulting film forms an attractive casing.

Food Industry. Pectin is used in the food industry for a variety of products. Films of the calcium sodium pectinate type and others made with different cations offer possibilities in preserving frozen foods, cheese, fish, etc., and as an anti-sticking or glazing agent for dried or candied fruits. It is also used as a stabilizer in salad dressings, catsup, table sauces, mayonnaise, puddings, and ice creams.

Pharmaceutical. Pectin possesses a multitude of properties which have potential value in the medicinal field. Numerous contributions on the use of apples for the treatment of gastro-intestinal disturbances have been made. Malyoth (28) suggested that the efficacy of raw apples was due to its pectin content. Winters and Tompkins (50), in controlled experiments, observed that pectin-agar in a mixture of dextrimaltose is far more effective than scraped raw apples in the treatment of infant diar-

rhea. Pectin, when combined with metals, forms compounds referred to as pectinates. Myers and Rouse (32) discuss one of these compounds, nickel pectinate, and show that clinical evidence has demonstrated its value in the treatment of acute and chronic bacillary dysentery, acute ulcerative colitis, and infected wounds. Pectinates of nickel, cobalt, manganese, lead, zinc, copper, calcium, and silver have been discussed by Arnold (2) and their bactericidal action shown.

Calcium pectinate films may be used in surgical dressings in the manner of celluronic acid gauzes. Pharmaceutical pastes and ointments can be stabilized with pectin and various medicants incorporated in it.

Miscellaneous. The fire-retardant properties of metallic pectinates make them useful in film-coating preparations for use on flammable surfaces or as films for use as decorations or draperies. Pectin can be used as an emulsifier for various oils, such as essential oils, castor oil, mineral oil, cottonseed oil, and olive oil and for tree-spray preparations. Glue and mucilages also are made of pectin and pectates have been used as creaming agents for liquid latex, as well as for hardening steel.

Other Potential By-Products of Citrus

Several potential by-products, that could be produced commercially, will be discussed briefly to show how they could increase the overall value of citrus by-products.

Bioflavanoids. The glucosides, naringin and hesperidin, found in grapefruit and oranges offer an excellent possibility for development into a profitable by-product. Several million pounds occur in the annual Florida harvest, but almost none is recovered for use. The chemical industry has indicated that a potential market exists for large tonnages of these glucosides, which may bring a price that would make them a profitable by-product.

Since naringin yields naringenin, glucose, and rhamnose upon hydrolysis, it could be used as a source material for the preparation of rhamnose. The bitter taste imparted by naringin could be used in the preparation of beverage drinks and tonics. Naringenin, the product obtained by acid hydrolysis, may be further hydrolyzed by potassium hydroxide to yield *p*-coumaric acid and phloroglucin. These compounds may in turn be used to prepare antioxidants and other synthetic organic chemicals. U. S. Patent No. 2,748,107 "Glucoside Azo Dyestuffs" has recently been issued to the University of Florida for a process which utilizes the bioflavanoids as dye intermediates. Recently, considerable interest has been shown in Vitamin P-like compounds. They are generally thought to be a mixture of hesperidin and eriodictin and little is known of their physiological role in animal metabolism. Other flavanones have been effective for similar therapeutic uses, and in some cases naringin, or naringenin, has shown greater physiological activity than hesperidin. Possibly, therefore, the chemical similarity between naringin and components of Vitamin P will be used to better advantage, especially in light of its better solubility.

Beverage Base. The consumption of non-alcoholic bottled beverages in this country has created a multi-million dollar industry. In recent years beverages containing fruit juices have contributed to this volume. However, of the fruit juice beverages that have been introduced, only citrus beverages, orange, lemon, lime, and grapefruit, became widely popular. Citrus juices also have been blended with other competitive fruit juices, such as pineapple, banana, etc.

Wines, Brandies, Liqueurs, and Vinegar. Like every other fruit juice con-

taining sugar, citrus juices can be fermented into alcoholic beverages. Citrus wines do not necessarily possess the characteristics of the fruits from which they are prepared, in the same way that wines proper do not resemble the flavor of grapes from which they are fermented. By adding more sugar to the fermenting citrus juices, the alcohol content of the resulting product will also increase. If this wine is distilled, a good brandy can be obtained. Liqueurs can be prepared by adding sugar and flavoring extracts to the distilled product.

Superior table vinegars have been made from orange, grapefruit, and tangerine juices. They were made by an alcoholic fermentation of the juice, followed by conversion of the alcohol to acetic acid by the action of acetic acid bacteria under aerobic conditions. It is expected that citrus vinegars can compete successfully with wine vinegars now on the market.

Fermentation Products. The waste waters from a citrus processing plant contain one of the cheapest known sources of sugar. These sugars probably could be utilized by fermentation to produce various chemicals such as antibiotics, lactic acid, glycols, yeast, and various other products. To date, very little has been done to explore the potentialities of these wastes by fermentation processes. While the various possibilities for the utilization of these sugars is unknown, they seem to offer a most interesting line of research for the profitable disposal of citrus wastes.

Miscellaneous By-Products. While the foregoing examples are some of the most striking possibilities of what can be done in a by-product operation, there are still other interesting possibilities that should not be overlooked. Other products not manufactured now but with possibilities worthy of development are ascorbic acid, citric acid, and inositol.

The recovery of inositol from citrus fruits is being investigated. Its principal market thus far has been in the pharmaceutical industry; however, it is thought to have important applications as a chemical raw material.

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Utilization Abstracts

Japanese Floor Mats. Mat coverings for floors in most Japanese homes are woven from igusa, *Juncus effusus* L. var. *decipiens* Buch. Cultivation is largely confined to the reclaimed lands (shinden) of Okayama Prefecture. The mats are filled with straw and may be used for mattresses for bedding as well as for floor covering. The inability of the mats to withstand concentrated weights accounts in part for the characteristic lack of furniture in Japanese homes.

Igusa is an important cash crop on shinden lands. There is the extra advantage that it may be grown as an off-season crop, although its late maturity may reduce a subsequent rice harvest 10 to 40 percent. Planting is done in December or January and harvesting in the middle of July.

Immediately after harvesting bundles of igusa are cleaned of weeds and shorter stems and dipped into pools of water to which has been added a high-lime-content clay. The clay forms a fine powdery coating on the stems and assists in even drying and production of the most desirable light green color. If ideal weather prevails, drying is completed in about two days, reducing the weight by about 70 percent. Rain at drying time can mean a serious loss of the harvest.

Although igusa is a crop with high demands for labor and fertilizer and with quite a speculative market, it can provide an extra income for Japanese farmers. Another rush species, *Juncus communis*, is sometimes used as an inferior substitute for the preferred *J. effusus*, var. *decipiens*. (Curtis A. Manchester, Jr., *Economic Geography 34: 47–63. 1958.*) (D.J.R.)

Rattans. Rattans or canes are long, slender, and flexible stems of certain scandent or trailing Indo-Malayan palms (*Calamus, Daemonorhops, Plectocomia*). The stems, usually cylindrical and of uniform diameter, may exceed 200 feet in length and vary in thickness from ⅛ inch to as thick as a man's arm. Canes are used for furniture frames, walking and polo sticks, alpenstocks, umbrella handles, baskets, and as ropes and suspension-bridge cables. Split cane is used for seats and backs of chairs and sofas. The "pith" left over after removal of the surface layer is cut into strips and utilized for furniture, sieves, and mats. Refuse is ground and sold for stuffing and packing, and for making rough cordage, matting, etc. Canes are exported from Malaya, Indonesia, Burma, and India. Malayan canes are considered to be the best. A cane is ready for harvesting when the lowest portion of the stem is exposed by the loosening of the leaf sheaths. The terminal six feet of the stem are discarded, and the rest is cut into 16-foot lengths, bent, dried, and treated in various ways. The outer silica layer is removed by rubbing the cane with a knife, a sharp piece of bamboo, or on rough bark of a tree. The cane may also be steeped in water, rubbed with sand, and dried. After desilication the cane is bleached by fumes of burning sulphur to get the desired creamy color. The cane's natural luster is then restored by polishing with a soapstone or with a woolen rag on which have been placed some siliceous hairs from bamboo leaf sheaths. Some canes may be smoked over a fire and then rubbed with coconut oil to give them a reddish-brown color. Finally, canes are sorted into different color and size classes, tied into bundles of 100 each, and stored for market. (R. L. Badhwar, A. C. Dey, and S. Ramaswami, *Indian Forester 83(3): 216–223. 1957.*) (JWT)

Rice Production in Afghanistan

Rice, Afghanistan's third most important crop, is produced in every province. Although about thirteen varieties occur in the country, for marketing purposes two main classes are recognized. These two, "Loke" and "Mai-een", are differentiated on the basis of grain size, color, consistency, and distribution.

ARNOLD KROCHMAL [1]

It is hard to visualize an Afghan meal without some rice dish, from simple boiled rice with mutton tail fat (rogon) to more elaborate dishes such as Qabeli, a combination of rice, grated carrots, and raisins. Almost as much as in neighboring China, rice is a dietary mainstay.

Rice is grown in every corner of Afghanistan, from the desert-like provinces of Kandahar and Farah in the south to the cold and snowy northern provinces. Rice is the third most important crop after wheat and corn (*Zea mays*). 278,881 tons were produced on 646,833 acres in 1953, the most recent date for production figures. The estimated yields in Table I give a good indication of the widespread distribution of this crop in Afghanistan.

Although most Afghan rice grows at lower and warmer elevations from 1,000 to 3,000 feet, it has been reported (1) above 6,000 feet.

Farm yields are low in comparison with American yields. The average Afghan producer harvests 40 to 50 seer (seer=16 pounds) per jarib (0.5 acre) for a yield of 1,200 to 1,600 pounds per acre.

[1] Director of Research and Horticulturist, University of Wyoming Team in Afghanistan.

TABLE I

ESTIMATED YIELDS OF RICE IN AFGHANISTAN *

Province	Yields in tons			3-year average
	1331 (1952)	1332 (1953)	1333 (1954)	
Kabul	39,132	34,924	35,312	36,456
Kandahar (and Girishk)	3,477	2,529	2,212	2,736
Herat	11,519	8,813	8,115	9,482
Mazar-i-Sharif	1,837	1,894	1,912	1,881
Kataghan	95,319	93,450	97,149	95,306
Eastern Province (Jalalabad)	85,512	70,092	69,557	75,053
Southern Province (Junobe)	6,231	6,772	6,552	6,508
Maimana	7,570	7,350	8,122	7,680
Farah	1,581	1,150	1,102	1,277
Badakhshan	2,881	2,807	3,211	2,966
Parvan	25,613	25,285	23,152	24,683
Ghazne	25,324	26,515	28,427	26,755
	305,996	278,881	284,823	

* Note Fig. 1.

Fig. 1. Afghanistan rice yields in tons by provinces. Figures are averages for three years.

Fig. 2. Distribution of rice varieties in Afghanistan. See Table III.

American rice is produced at the rate of about 2,200 to 2,800 pounds per acre. The difference lies in the use of fertilizers, machine harvesting, and selected varieties in American agricultural practise.

Rice is usually part of a two-crop rotation. In Jalalabad Province it is grown on the same land as wheat; it is sown from April to June and harvested in September or October. After harvest is complete, winter wheat is sown in the same fields. In northern Afghanistan rice is planted any time from May 5 to June 22 and harvested from the last week of September to the last week of October. It is usually followed by winter wheat. In the western area around Herat rice is sown in rotation with clover.

Afghanistan Varieties

Although many varieties of rice are produced in Afghanistan, the market recognizes two main classes, "Loke" and "Mai-een". A comparison of these is given in Table II.

TABLE II

CHARACTERISTICS OF RICE CLASSES

"Loke"	"Mai-een"
5.0–5.5 mm. long	7.0 mm. long
Starchy	Flinty
Brown, tan	White
Widely grown	Limited to eastern Afghanistan from Laghman west to Kabul and Khanabad; rarely in Kandahar and Jalalabad

Vavilov (2) has provided a botanical classification of rice varieties of Afghanistan under the two market classes of "Loke" and "Mai-een" (Table III).

Regional Distribution of Rice in Afghanistan

1. Badakhshan
2. Bala Murghab
3. Bamion
4. Banu
5. Charikar
6. Farah
7. Herat
8. Jalalabad
9. Kabul
10. Kandahar
11. Kataghan
12. Khanabad

TABLE III

VAVILOV'S CLASSIFICATION OF AFGHANISTAN RICE VARIETIES (2)

	Color of awn	Length of grain (mm.)	Distribution (numbers refer to regions in Fig. 2 *)	Remarks
"Loke" (5–6 mm.)				
1. Var. *vulgaris* Körn.	.....	5.1–5.2	4, 5, 7, 10, 12, 13, 15, 18	
2. Var. *dichrae* Batal.	Slightly reddish	5.8–6.0	1, 2, 5, 6, 7, 9, 11, 17	
3. Var. *erythroceras* Körn.	Slightly bluish	5.5	7, 8, 9, 13	
4. Var. *ianthoceras* Körn.	Reddish-yellow	5.2–6.0	12, 13, 19	
5. Var. *melanothrix* Al.	Slightly bluish rarely blackish	6.0	4, 12, 16	
6. Var. *amaura* Al.	Bluish	6.0	3, 9, 20	
7. Var. *rubra* Körn.	Whitish	5.6	4, 12	
8. Var. *italica* Al.	Whitish	5.6–6.0	9, 15	
9. Var. *pyrocarpa* Al.	Reddish-yellow	5.0	9, 13	
10. Var. *caucasica* Batal.	Blackish-red	5.5–6.0	6, 8	
"Mai-een" (7 mm.+)				
1. Var. *aristata* Vav.	Straw-colored	7.0	8, 9, 12, 14	Awns of spikelets 15–45 mm. long
2. Var. *mutica* Vav.	.....	7.0	8, 9, 12, 14	Spikelets without awns
3. Var. *brevearistata* Vav.	.....	7.0	8, 9, 12, 14	Awns of spikelets very short

* Note numbered list which follows.

FIG. 3. Terraced rice field in the Laghman Valley, Jalalabad Province, the harvested rice lying in windrows, drying.

13. Khunjan
14. Kilat
15. Kunana
16. Kunduz
17. Logar
18. Subzwar
19. Talakan
20. Tirah

Preparation for Marketing

The preparation of rice for marketing is a village enterprise, but it should be noted that the term "village" as used in Afghanistan is different from that in the United States. In Afghanistan a "village" is a family unit of several walled compound areas located close to each other. The question of geographical proximity does not enter into a village make-up. A neighbor's compound may be only fifty feet away; but if he is of a different family, he is in a different

FIG. 4. Rice is hardened for de-hulling by mixing the green rice with sand heated in large mud ovens. The close-up of a villager going through this operation shows a little niche to the uper left which is used to hold kerosene lanterns when the work goes on at night.

FIG. 5. A common type of water-operated mill used in the eastern villages to remove the hulls. Water forced into a narrow channel turns a simple water-wheel and gear mechanism, alternately lowering the two long arms with their vertical pounding attachments. The vertical "pounders" fit small holes in the floor where the oven-dried rice is placed.

"village". Thus, a number of families may have adjacent compounds, but only those related to each other will constitute a village. The work is done on a communal basis, and the profits, if any, are divided in a manner decided by the village chief, usually a senior member of the family.

Rice is cut in the fields with hand sickles and stacked in windrows (Fig. 3). When it has dried sufficiently, it is moved to large stacks and then threshed by teams of oxen or infrequently by donkeys. This is a rather inefficient method, as a large quantity of the grain is lost during the threshing. As threshing continues, the grains are removed for hardening. This may be done in different ways in different villages. A common method is to prepare warm sand in mud ovens (Fig. 4) and then to mix the sand with the rice grains. The heat hardens the grains and prepares them for the next step, removal of the hulls.

Hulls are removed in a water-driven mill (Fig. 5). To get sufficient force to operate the rather bulky and unwieldy de-hulling device, water is forced into a narrow channel. A simple water wheel and gear arrangement alternately raises and lowers long arms which, in turn, pound small amounts of rice in a depression in the hard dirt floor of the mill. After screening the grain to remove chaff and dust, the finished product is placed in crockery jars for movement to markets.

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Utilization Abstract

Ceylon Oil of Citronella. About 35,000 acres of citronella grass (*Cymbopogon nardus*) are under cultivation in extreme southern Ceylon. The island produces up to 1,390,000 pounds of citronella oil annually. This oil is perhaps the most important volatile oil of Ceylon. The direct steam type of distillation is most commonly used, and stills are usually located at the base of hills where sufficient water is available. Grass leaves are harvested every 3 or 4 months, each cutting yielding about 14 tons of leaves per acre. Leaves, after proper drying, are introduced into stills, and distillation of each charge lasts about 4 to 5 hours. Steam passes through the still and, carrying with it the volatile oil, is condensed in a series of water-cooled tubes. Oil and water are separated in the receiver. Ceylon citronella oil has attained a bad reputation because of adulteration. Common adulterants are native fat (probably coconut oil), alcoholic spirit, and mineral oils. Citronella is widely used in cosmetic and soap perfumes, in some pharmaceutical preparations, for mosquito and leech bites, and as an insect repellant. (M. G. De Silva, *Soap, Perfumery & Cosmetics 30(11)*: *1160–1163. 1957.*) (JWT)

The Durra Complex in the Central Highlands of Ethiopia

The Eastern Galla of Ethiopia have developed advanced agricultural techniques of rotation, terracing and irrigation with Sorghum vulgare (durra) as the major field crop. Crops of secondary importance in the durra complex are corn (Zea mays), barley, peanuts, sesame, field-peas, beans, and fenugreek.

CLARKE BROOKE [1]

Introduction

The majority of people in Ethiopia live in small farm villages scattered throughout the Ethiopian Plateau and the Central Highlands (Fig. 1). In these temperate, moist uplands two grossly different systems of agriculture are practiced—the production of cereals with the use of the plow and the cultivation of root crops with the hoe and related implements. W. Stiehler has pointed out that these two planting systems in Ethiopia are historically distinct and that each characterizes one of the two great cultures of northeastern Africa—the Semitic and the Cushitic.[2]

Agriculture in the Central Highlands is carried on principally by tribes of the Eastern Galla, Late Cushites, who practice plow cultivation and give preference to durra grain sorghum over all other crops. Although agriculture in the Central Highlands has several unique features, its outstanding characteristic is the dominant position of durra (*Sorghum vulgare*) in the economy. Grain sorghum is widely distributed in Ethiopia, but, with the exception of the Central Highlands, it is a major crop solely in the lowlands. Other cereals (especially barley and teff on the northern Ethiopian Plateau) are preferred in highland, grain-cropping systems.

A large number of products are grown in the Central Highlands and involve several systems, i.e., field cropping, gardening, and tree and shrub cultivation (Table I). Although all of the three systems are a part of the agriculture of nearly every rural village in the Central Highlands, field crops by far are of greatest importance. Durra and the other field crops which are interplanted with it—or are associated with the field rotation system of durra culture—comprise the "durra complex" of the Central Highlands.

The most densely populated areas in the uplands of Ethiopia, for reasons of topography and climate, are above approximately 5,500 feet of elevation. Most agricultural settlements in the

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[2] W. Stiehler, "Studien zur Landwirtschafts und Siedlungsgeographie der Äthiopiens", Erdkunde 2: 257–282, 1949, noted in Geogr. Rev. 46: 271–272, 1956. Stiehler held that the use of the plow and the planting of grains and other seed crops (as practiced in the central and northern parts of the Ethiopian Plateau by Amhara and Tigre peoples) is the more recent planting system introduced by Semitic migrants from southern Arabia sometime before the first millenium B.C. He considered that the use of the hoe in the cultivation of vegetatively reproduced plants—especially the banana-like ensete, *Ensete edulis*—is characteristic of the older Cushite culture, centered today in the area of the Sidama tribes in the southern Ethiopian Plateau and in a small area of the southwestern section of the Central Highlands. See also Helmer Smeds, "The Ensete Planting Culture of Eastern Sidamo, Ethiopia", Acta Geographica 13(4): 1–39, 1955.

Central Highlands have relatively cool, wet summers, very dry winters, and a small annual temperature variation. They receive 32 to 55 inches of rain annually. In the altitudinal zone of these areas the mean maximum temperature is from 72° to 80° F. and the mean minimum is between 52° and 59° F. Villages lower than about 5,500 feet have somewhat higher temperatures and usually less than 32 inches precipitation during the year.

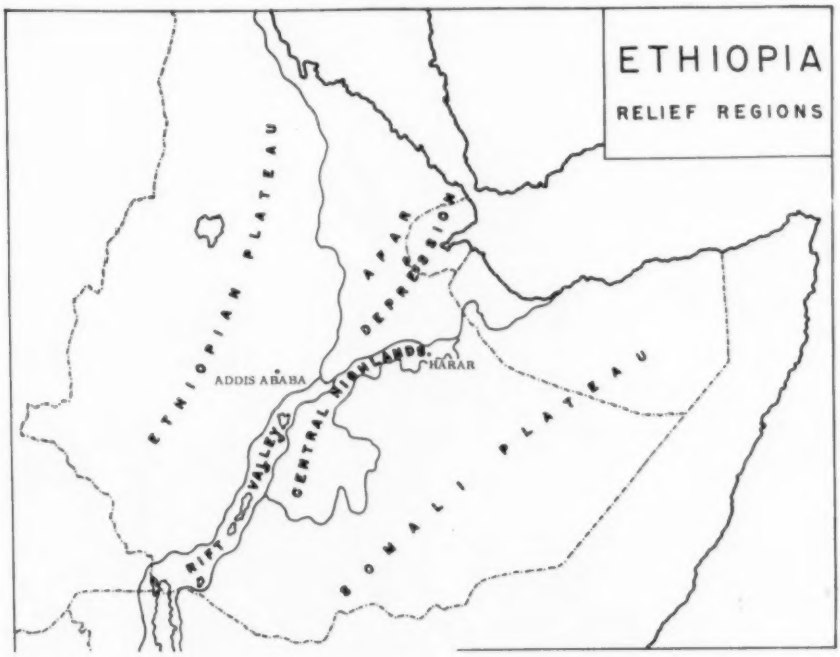


FIG. 1.

Basalts, tuffs, and in some areas intruded granites are the most common rocks in the region. Most settlements present varied slope conditions, including steep gradients as well as gently inclined surface areas. Although grasses predominate in the associations of native vegetation, there is evidence that woodland formerly was much more extensive. Friable, well-drained, reddish and reddish-brown loams are the most widely distributed soil types. The soils are medium to strongly acid in reaction and have a low content of organic material, phosphorus, potash, and nitrate. Sheet erosion is severe on cultivated hillsides.

The Major Crop—Durra

Under the generic name "bishinga" the Eastern Galla recognize many different types of durra, *Sorghum vulgare* (Fig. 2). Not only does durra occupy greater acreage than other cultivated plants in the region, but, without doubt, its yield exceeds the combined total of all other grains. Major factors in its popularity are its tolerance for a variety of ecological conditions, especially its

FIG. 2. White "wagare" is one of the principal varieties of durra in the Ethiopian highlands.

resistance to drought, and the relatively simple cropping techniques necessary for its cultivation.

The preparation of fields which have been fallow for several years involves breaking the turf with bored-stone digging sticks [3] during the dry season of the year, six weeks to one month before the rains are due (Fig. 3). The clods are overturned to bring up and kill the grasses or other perennial weeds before the second plowing. Otherwise, to prepare the seed bed the farmer plows his field [4] after the first rains in March, and nothing more is done until he is ready to seed. First sown are the longer-maturing varieties on a small part of the field or fields, for his holdings are usually separated. The principal variety of sorghum for the area is sown during the month of April in the villages above approximately 5,800 feet elevation and during May in the lower areas. A much smaller area is seeded to fast-maturing durra as late as June or July. The seeds, carried in a goatskin, are sown broadcast and covered the same day by a second plowing (Fig. 4).

On hillsides planted to durra and other crops the Galla frequently construct rudimentary, broad drainage terraces which are called "daga". These vary in width, from twenty to thirty feet; the vertical distance between levels is small, only one or two feet. In the middle section of the Central Highlands bench terraces have been constructed which are about six feet wide, with rock retaining walls. Many of similar type are found on steep hillsides in the vicinity of Harar, but most of them are abandoned or planted to tree crops only.

Corn (*Zea mays*) is usually sown with durra, especially in fields near the dwellings. Beans, gourds, melons, peppers, fenugreek, and the other field crops discussed below are cultivated with durra in the rural settlements, including peanuts in the eastern section of the Central Highlands as shown in Fig. 5.

The farmer will thin his durra (and corn, if intermixed) to a spacing for in-

TABLE I

CULTIVATED PLANTS IN THE CENTRAL HIGHLANDS OF ETHIOPIA

A. The durra complex of field crops:
- Durra (grain sorghum), *Sorghum vulgare*
- Corn, *Zea mays*
- Barley, *Hordeum distichon*, *H.* var.
- Peanut, *Arachis hypogea*
- Sesame, *Sesamum indicum*
- Field-pea, *Pisum arvense*
- Fenugreek, *Trigonella foenum-graecum*
- Bean, *Phaseolus* spp.

B. Miscellaneous field crops:
- Teff, *Eragrostis abyssinica*
- Flax, *Linum usitatissimum*
- Wheat, *Triticum abyssinicum*
- Emmer wheat, *Triticum dicoccum*
- Niger seed, *Guizotia abyssinica*
- Lentil, *Lens esculenta*
- Chick-pea, *Cicer arietinum*
- Safflower, *Carthamus tinctorius*

C. Garden crops:
- Tobacco, *Nicotiana tabacum*
- Sweet potato, *Ipomoea batatas*
- Melon, *Cucumi melo*
- Gourd, *Lagenaria vulgaris*
- Red pepper, *Capsicum annum*, *C. abyssinicum*
- Onion, *Allium cepa*
- Potato, *Solanum tuberosum*

D. Tree and shrub crops:
- Coffee, *Coffea arabica*
- Khat, *Catha edulis*
- Fruits
  - Banana, *Musa sapientum*
  - Orange, *Citrus sinensis*
  - Guava, *Psidium guaïava*
  - Pomegranate, *Punica granatum*
  - Custard-apple, *Anona* spp.
  - Peach, *Prunus persica*
- Henna, *Lawsonia inermis*
- Castor, *Ricinus communis*

[3] For some historical and cultural implications of the use of this implement in the Central Highlands see J. Desmond Clark, "The Use of the Bored Stone in Abyssinia", Man **44**: 31–32, 1944.

[4] A team of oxen can plow about one-half to three-quarters of an acre per day.

dividual plants of about one and one-half feet by two feet on the most fertile soils. In other places the plants are spaced farther apart. Plants which fail to flower and others which are uprooted in thinning are taken to the edge of the field or to the house to be used for cattle feed.

In each village the general practice is to plant durra in the same field year after year until the soil is almost exhausted of fertility. Compost is scattered about the field after the harvest and is sometimes plowed under, but it often is left undisturbed on the surface until the first plowing. This practice will give increased yields for several years, but eventually, when application of compost is no longer effective, the farmer will reluctantly sow crops other than sorghum. Eventually he will let the field lie fallow for two or three years and then plant peas or another legume for one harvest. It was reported that durra and corn may then be sown on this "new land" the following year and will give "good" yields for several years without application of compost.

This, in brief, is the land rotation "system" of the Eastern Galla, in which the land is cleared, planted—principally to durra—for an indeterminate number of years, finally allowed to lie fallow, and eventually, to revert to pasture and then is recleared for durra production once again. The period of the cycle of rotations varies greatly from place to place, in accordance with differing conditions of the rate of soil loss and depletion, the rate of soil rejuvenation, popu-

FIG. 3. Before "new" or "bush-fallowed" land or pasture is plowed, the turf is first broken and turned by groups of men using the bored-stone digging sticks.

lation pressure, etc. For the densely populated Harar region the complete cycle averages probably from twelve to fifteen years.

In December or January the durra is cut by hand sickle several inches above the ground, and the long stalks with their head of grain are placed on the ground. After two days the heads are easily cut from the stalks and placed in neat piles in the field. Large heavy heads are separated to be used for seed. Men working cooperatively in groups do most harvesting tasks.[5] However, the women gather the heads and stack them on a bed of sorghum stalk in the field. The heads of grain remain there for about a week to allow further drying and then are carried by the women, or by donkey, to the place of threshing. A level space of ground near the field will serve all of the farmers of the village for this purpose.

The space which forms a rectangular area of about two or three hundred square feet is wetted, pounded to make it compact, allowed to dry, and then covered with a layer of fresh cattle manure, which dries to a smooth, hard surface. Around the margin of the thrashing floor each family has stacked its sorghum. All men of the village work cooperatively at this task, and, divided into two or three groups, they beat the heads of grain with the long threshing stick. When one lot has been threshed,

FIG. 4. During the second plowing of the year (usually in April) durra is sown broadcast as in the photograph by the man on the left. Yoked oxen pull the Ethiopian plow, the prototype of which probably originated in southern Arabia.

[5] Various harvesting techniques in the Central Highlands are summarized in M. Nasturcci, "La raccolta degli cereali al Harar", L'Agricoltura Coloniale 6: 370–374, 1939.

it is pushed to the side where one man gently sweeps the surface of the material, picks out and discards the coarser stuff, then winnows the remainder using first a shallow basket and then a paddle.

The stubble is left in the field, plowed under during the preparation of the seed bed for the next planting, and finally collected and removed from the field to the house for fuel during the cultivation of the young sorghum. If stubble is left in the field beyond late April or early May, the old roots will serve as breeding places for termites which will attack the new sorghum crop. This practice poses problems for soil management. Removal of stubble is a factor in the low content of humus and in the erosion of soils in the region.

Data of crop yields are difficult to obtain in areas of subsistence agriculture. From an agricultural census and field measurements taken by the writer in three rural villages of the Central Highlands the estimated yields for durra cultivated in these several settlements were acquired. The villages ranged in elevation from 5,250 to 6,720 feet above sea

FIG. 5. A map of a small settlement (population 49) at an elevation of about 5,500 feet in the eastern section of the Central Highlands of Ethiopia. Even in this sub-humid, lower part of the Highlands (average precipitation about 30–32 inches annually), a great variety of crops is grown. However, durra interplanted with peanuts, corn, and other plants occupies by far the greatest acreage. Slope in the western part of the settlement is one or two degrees, increasing to eight or nine degrees in the northeast.

level, and, not surprisingly, the data suggest a correlation between yield and elevation-precipitation values. The calculations indicate that the annual average yield in durra in the wetter parts of the Highlands (say above 5,800 feet elevation) is 18 to 25 bushels per acre. In the lower and drier settlements the yield for an "average" year is considerably less, from 6 to 12 bushels per acre. It is estimated that 200 pounds of straw are recovered for each 100 pounds of grain.

Usually the best grade of grain for each variety of durra is separated for storage in pits excavated in the yards near the houses. The capacity of the pits varies from 4,000 pounds to 15,000 pounds of grain. The remainder of the grain is stored in fiber or manured baskets within the house.

Although grain sorghum is a very hardy plant and seemingly free of many of the diseases which afflict other cultivated grasses, both severe drought and exceedingly heavy rains will damage the crop. Insects are a serious problem in all settlements, attacking both the growing plants and the stored grain. Various larvae may bore the stalk or destroy the leaves of young plants. Every three or four years legions of the army worm (*Laphygma exempta*) appear in May and June, causing grave damage. The migratory locust usually pass through the Central Highlands after the harvest, but infrequently they arrive early and may destroy the growing plants.

The stalks are used for fuel and for cattle feed. Most farmers strip the leaves of the plants before cutting and tie them in large bundles which are stored for feed. Long stalks are used in all Galla settlements for roof construction and to build small structures such as pens and temporary shelters. Parts of the stalk and leaves uneaten by the livestock during the night are collected each morning (with the droppings of animals kept in the house) and placed on the compost pile.

Nearly all of the grain is stored to be used by the family as the basic food, principally in the form of flat bread, thick soups, and porridge. The bread is called "buddena" and is usually made from grain sorghum by the Eastern Galla. To a lesser extent, maize, teff, and barley (mixed with durra) also are used for this food.

Relatively little of the grain is sold, the Eastern Galla preferring to keep any surplus in the pits as insurance for partial crop failure. The grain is bought by Arab merchants, some of whom travel to the rural villages to buy; others stay in the nearest market center and pay a small premium when the grain is brought to their place of business. There is great variation of price from place to place in the Central Highlands and from month to month throughout the year. Grain is sold by the metric quintal, 220.46 pounds. A quintal of durra grain during the harvest sells for about E$7.50 (approximately U. S. $0.70 per bushel) at the threshing ground. One month later the price is about E$10.00 (U. S. $4.00), and during June and July, E$15.00 per quintal. Better prices are offered by merchants at the rail center of Dire Dawa, and farmers who sell some of their crop transport the grain by donkey to this town. The farmers sell only the "challa", the best grade grain of the sorghum varieties.

Secondary Crops

Corn (*Zea mays*), intermixed with grain sorghum is the second-most important crop in the durra complex. Two varieties were noted in the settlements: *minjar*, a flint which matures about five months after germinating and is sown in both fields and gardens, and *bukuri*, a sweet corn, or possibly, a cross-fertilization of sweet and flour, also planted as a field and garden crop. If planted as a

field crop, minjar is sown with grain sorghum in April and May. Bukuri, which ripens in about 120 days, is planted in early June in the gardens or in late May if sown with fast-maturing varieties of durra.

In field culture corn is sown with grain sorghum; but because durra is the preferred crop, it outnumbers corn by a ratio of seven or eight to one, i.e., if fifteen pounds of mixed sorghum and corn seed are sown to one acre, somewhat less than two pounds of this quantity of seed will be corn. Thus, since it occupies one-seventh or less of the cultivated field, the average yield is low, probably about 2 to 4 bushels per acre. For a good year, corn without other crops interplanted should yield 15 to 25 bushels per acre. Corn is more sensitive to drought than grain sorghum, and its yield is greater in the higher, wetter settlements than in the lower, drier villages. But above approximately 7,000 feet, cool nights (below 55° F.) retard the maturing of the plant, and corn yield as well as the acreage planted rapidly decrease above this elevation.

Although it is widely and irregularly spaced as a field crop, in gardens corn grows at close intervals, about two feet by two feet spacing. Gardens are cultivated and fertilized with compost more often than field crops. After three to six harvests of corn and grain sorghum, fields are rotated to one crop of barley or to some other small grain; but gardens, fertilized more frequently, are inter-planted with corn and various vegetables year after year for an indefinite period of time.

Corn matures more quickly than grain sorghum and is harvested from two to three months before durra, i.e., during late August and early September at elevations to approximately 5,600 feet and from late September through November in higher settlements. The stalks of the ripened plants are cut a few inches above the base and placed to dry in conical stacks for eight to twelve weeks until the durra is harvested. Corn is threshed in the same manner as grain sorghum. Large ears are retained for seed and are stored unshucked next to the roof inside the house.

Fresh ears are roasted. The grain is prepared to make bread, soup, and porridge, although grain sorghum is preferred by the Eastern Galla for these foods. Corn is softened by storing in a container of water overnight before it is pounded in the mortar to remove the husks and ground to flour with the hand mill. Like durra, some corn is parched to be eaten as a snack. Parts of the plant not used for food are fed to stock or thrown on the compost pit. However, a farmer will commonly stack dried stalks near his house as a source of fuel.

Barley (*Hordeum distichon, H. var.*), is an important highland crop at elevations above approximately 7,500 feet in the Central Highlands and on the Ethiopian Plateau, but at lower areas it occupies relatively small acreage in the durra complex, chiefly small fields of crop rotation and in plots planted late in the season after a partial failure of sorghum.

Six-rowed barley (*H. vulgare*) is common in the eastern section of the Highlands and other high areas of Ethiopia. A two-rowed variety (*H. distichon*) with white seeds and two types of four-rowed barley, which are probably of the "Abyssinian intermediate" variety, are extensively grown in the middle and eastern sections of the Central Highlands [6].

Barley may be planted from June to early August. As a rotation crop, it is usually sown in June and harvested four months later in October, a full month or two before the major durra harvest. Two harvests per year are not unusual in

[6] R. Ciferri has classified Ethiopian barleys in Nuovo Giornale Botanica Italiana **47**: 424–435, 1940.

some parts of Ethiopia where moisture and soil conditions are favorable, but only one planting per year is made by the cultivators in most of the settlements.

Almost without exception other crops are not planted with barley. Farmers reported that sometimes barley might be planted amidst a young tree crop such as khat but that even this practice was rare.

Compost is distributed over a field to be sown to barley before the first plowing, when the seed is cast by hand and covered by furrows. The crop is given no other care except occasional weedings.

Except in the highest villages barley is never replanted in the same field the year following its harvest. It is the usual practice that grain sorghum follow cultivation of barley, for durra and corn have preference as food crops. The farmers of lower settlements reported that barley is useful only when the two coarse grains fail to produce, i.e., in fields where soil fertility has reached a very low level or when young sorghum has been seriously damaged by weather or insects and barley is planted as an emergency crop because of its fast-maturing character.

Ripe barley is cut to give a long stem, tied into sheaves which are stacked upright in its field on a bed of grass or grain sorghum stalk. A temporary wall of durra stalks is constructed around the stack, and the leaves of grain sorghum and corn cover the top to protect the grain from weather and vermin. It is allowed to dry for about a month, and then women carry it to the threshing ground. Oxen or donkeys are driven around the barley to loosen the grain by trampling. Unloosened seeds are stripped by hand, and the barley winnowed, placed in burlap sacks, and carried by donkey to the house.

Informants in the villages reported yields equivalent to approximately 40 to 50 bushels per acre. These figures appear to be too high, but there was no means to verify this information.

Peanuts (*Arachis hypogea*) are a major cash crop in the durra complex of the peoples east and south of the city of Harar at elevations between five and six thousand feet. The map (Fig. 5) shows the distribution of crops for a typical settlement within the region. Almost all peanuts are sold to merchants for processing to oil which is both exported and used locally for cooking. The one variety bears medium-sized pods and is the "runner" type, i.e., with stems more or less procumbent. A good deal of the area in which peanuts are grown is of red, sandy, or sandy-loam soils for which the plant is well suited.

Peanuts are usually planted in April, but occasionally the seeds are sown in March if that month is unusually rainy. The crop is not ready to be harvested until late November, seven months after planting, an unusually long time for peanuts grown in the tropics.

It is customary to plant peanuts with grain sorghum and corn, but the growing peanuts must not be unduly shaded. For this reason clusters of young durra and maize are thinned by transplanting some of the shoots in order that they may be widely spaced.

The cultivation of the peanut-durra-corn association is more laborious than that of only the two coarse grains. The three interplanted crops require many hours of work with the heavy hoe, thinning and transplanting the cereals and spreading fresh earth over the exposed stems of peanut plants.

It is the practice of the Galla to seed any one field with peanuts (and durra) for two years, followed by an equal period of time in which only grain sorghum and maize are planted. It was reported that if peanuts are planted year after year without interruption the yield declines seriously by the fourth year.

The average yield is probably between

five hundred and six hundred pounds of peanuts per acre. The Eastern Galla usually sell almost all of their harvest, retaining only a small quantity for seed. Occasionally peanuts are roasted, the shells removed, and the nuts pounded in the mortar to a paste, which, with chopped onions, peppers, and salt, is made into a thick soup. Or, of course, peanuts may be eaten from the shell after roasting.

Throughout the year all peoples of the Central Highlands buy peanut or other vegetable oils for cooking. The dried stems are fed to cattle after the harvest, but the pressed cakes have no market for feed or other purposes.

Sesame (*Sesamum indicum*) is another oleaginous cash crop of the Eastern Galla. Most of the seed is probably sold to the operators of small presses, but part of the production of dry seed is exported from Ethiopia to foreign markets. Sesame is planted in the same region as the peanut. It appears to need less moisture than the peanut, however.

The preparation for seed bed, planting, and cultivation of sesame is the same as for the cereals. However, sesame is usually not sown or interplanted with other crops, but it is infrequently sown with grain sorghum, in which case the sorghum spacing must be even greater than when durra and peanuts are interplanted. A field is planted to sesame usually only for one or two harvests; grain sorghum and corn follow for at least two more years. It is sown in June and is ready for cutting by mid-December.

The plants are cut with the hand sickle when not quite ripe, care being taken not to invert the capsules so that no seed will be lost. Several strips of bark are tied around bundles of the cuttings which will stand erect in the field to dry. The bundles of plants need only be inverted to yield most of their small seeds which are stored in manured barrels within the house.

The plant appears to be hardy, disease resistant, and does not attract animal or insect predators.

Very little sesame is eaten, although it can be roasted and prepared in foods in a manner similar to linseed. Nearly all is sold to merchants for its oil content. Arab merchants who buy large quantities of oil seeds travel about the country making their purchases from the farmers. Buyers pay at the rate of about E$30.00 (U. S. $12.00) per quintal for the seed. It is estimated that average yield is about 350 pounds per acre.

Field-pea (*Pisum arvense*), like chick-pea, is a minor legume in the Central Highlands. In many tropical highland areas field-peas are interplanted with other crops, but the Eastern Galla do not follow this practice. The cultivators in the villages stated that they consider field-peas the best crop to sow the first year on "new" land cleared for durra and corn production. Peas are planted in July and harvested in late October. Two varieties, "white" and "black", are cultivated. The type with whitish seeds is sold, and the dark seeds are used for food by the cultivator and his family. The seed stalks are separated from the plant by hand before the pods are fully ripened, stacked in the field, covered with grass, and allowed to dry for three or four weeks before separation by trampling with livestock. Winnowed, clean seed is stored in manured baskets within the house, and the stalk and leaves are fed to cattle. The light-colored seeds are sold in the market centers at prices which range from E$10 to E$20 (U.S. $4–$8) per quintal.

Fenugreek (*Trigonella foenum-graecum*) is a legume somewhat similar in appearance to peas. The seeds, which have a pungent odor, are prepared as broth which is fed to babies, young children, and to ailing cattle as a tonic. Fenugreek is sometimes planted in garden plots but more commonly is grown

at the border of a durra and corn field. Sowing takes place in July, and by November the crop is ready for harvest. The plants are uprooted and tied in small bundles which stand drying in the field for at least a week. They are then collected and placed in one large grass-covered stack until January, when other crops, as well as fenugreek, are threshed. The seeds are loosened from the pods by light blows with small beating sticks and are stored in a small manured basket. Very little fenugreek is sold. Most is retained to be used in food preparation, or, more likely, as a medication or tonic.

Beans (*Phaseolus spp.*) are the major leguminous crop in the durra complex common to all of the Highland rural villages. Their importance lies not only in the fact that beans are widely distributed throughout the Central Highlands, but also to the early maturity and low moisture requirements of the plant, which make it a dependable catch-crop when staple grains fail. In most areas two harvests are taken between April and December. Furthermore, the high protein content (24 percent) of beans is important to the diet of the people.

Several varieties of beans are found in each settlement. A type with white seeds brings the best price from the merchants, and in many settlements almost the entire production of white is sold for about E$15 (U.S. $6) per quintal.

Nearly always beans are interplanted with durra and corn, and the preparation of the seed bed is the same as for the grains. Bean seeds, interplanted with durra and corn, are sown broadcast in April. By mid-July the pods ripen, and whole plants are uprooted and carried to the edge of the field where a threshing floor has been prepared. The white seeds are separated and stored separately from the others, for it is the practice to sell this variety soon after its harvest. Immediately after the recovery of the crop sown in April the area previously planted to beans is reseeded once again. The seeds are scattered amidst the growing corn and sorghum and covered with fresh earth. The second crop of beans is harvested shortly before the durra matures, usually in late November.

Summary

The flourishing agriculture of the Central Highlands obscures the fact that the peaceful farm communities in the region represent a great transformation in the economic life of the people. Until 150 to 200 years ago nearly all of the Eastern Galla were pastoral. Camels, cattle, sheep, and goats supplied the needs of the then much smaller population. Animal husbandry is still an important element in the economy but is now subordinate to crop culture, for the population of the Eastern Galla today (1,500,000 est.) is far greater than that which could be supported by animal products.

An interesting aspect of agriculture in the Central Highlands is its relatively advanced techniques. The use of the plow, production and application of compost, knowledge of crop rotation, terracing, and irrigation [7] are features which are not widely found among cultivating peoples in Africa south of the Sahara. Much of this knowledge—including the cultivation of tree and shrub crops (especially coffee and khat) to a degree of importance unknown elsewhere in Ethiopia—was probably disseminated from the farming area around the old Moslem city of Harar, which for many centuries has been one of the great commercial and religious centers of northeastern Africa. The townspeople, called Harari, today

[7] Irrigation in the Central Highlands is limited to the relatively few places where topographic and drainage conditions permit the construction of channels or trenches which several times a year carry water from the main stream to land planted to tree or shrub crops. Field crops are rarely irrigated.

number about 10,000, speak their own unique Semitic language, and use farming techniques very similar to those of the Eastern Galla. Although the origin of the Harari is obscure, their system of agriculture has many features common to that in southern Arabia, a region which has maintained close religious and commercial ties with Harar for nearly 1000 years.

Like most other agricultural areas of Africa, more effective erosion-control measures are badly needed in the durra-complex planting culture. Interplanting affords a small measure of protection, but cultivated land on slopes should be ridged on the contours. Too often the preparation of the seed bed for field crops is cursory. Rather than spread fertilizing material over the field, the farmer tends to retain compost for long periods of time in order that others may be impressed with the evidence of his large number of livestock. Reduction in the number of livestock maintained in the Central Highlands would serve not only to arrest the erosion of grazing areas but would afford the return to the soil of crop residues which are used for feed. Strip cropping and strip mulching techniques also would be of value in the region. Many diseases common to durra and other cereals, could be controlled by treatment with seed disinfectants. Use of insecticides for infestations of the stem borer and the army worm would give a significant increase in yields.

Even in areas with the most favorable conditions for agriculture, the marketing system—almost exclusively controlled by Arab merchants—is a major factor in the low level of production for cash. Prices paid the farmer for his produce too often are unrealistically low in terms of a fair return to the cultivator and tend to inhibit his desire to produce beyond the subsistence level.

Nevertheless, there is evidence that trade is of growing importance in the Central Highlands. Especially in areas served by motor roads there is a prevailing tendency for increased production of cash crops. Every farmer is obliged to sell some of his produce in order to pay his taxes and to buy necessary staples such as salt, cooking oil, and cotton cloth. Today increasing numbers of farm families buy such things as German-made oil lanterns, Shell kerosene, and cheap Italian perfumes.

New or radical changes in the economy are not to be expected. The durra complex will continue to be dominant. But a greater measure of commercial agricultural production is sure to follow the gradual expansion of transportation facilities within the Central Highlands, which probably in time will bring the region into closer association with domestic and foreign markets.

BOOK REVIEWS

Evergreen Orchards. Second Edition. William H. Chandler. 535 pages. Lea and Febiger. $8.50.

"Evergreen Orchards" by William H. Chandler has now been revised after eight years of usefulness. The major changes comprise a reorganization into separate sections on dicotyledonous and monocotyledonous crops and a new chapter devoted to the pineapple. It seems strange to have a pineapple planting termed an orchard, but it is most helpful to have this comprehensive information on pineapple culture thus made available. The papaya chapter has been extended to include the passion fruit. The chapter on Tea, Coffee, and Cacao, which included a brief discussion of the colanut has been renamed Stimulant Crops. Short sections on guarana and yoca (the latter hardly qualifying as a cultivated crop anywhere) have been added to this chapter. Considerable shifting about of material has been done in the first three chapters; and some useful discussion has been entirely eliminated in the interest of space, for the revised edition is some 80 pages longer even so.

More important than these rearrangements, not all of which seem to be improvements, is the real revision of the information presented. In every chapter there is impressive evidence of the thoroughness with which the author has combed the horticultural literature and incorporated the findings of the past decade into the discussions. Chandler has always been primarily an apple man and has had scant first hand experience with most of the crops discussed in this book, although he has travelled widely to acquaint himself with some of them, e.g., his visits to Trinidad for cacao and to Hawaii for pineapple and passion fruit study. However, a lifetime devoted to deciduous fruits has given him a perspective from which to survey the culture of the evergreen fruits; and the horticultural problems are not so different that a really competent pomologist such as Chandler cannot analyze lucidly the factors of nutrition, climate, propagation, fruiting, and fruit handling. The strongest features of the book are the bringing together of available research reports on all these crops and the mature judgment exercised in assessing the potentialities of some of them.

This is a book without any rival in its field. There are two more extensive books on citrus culture alone and excellent bulletins from the agricultural experiment stations covering a few of the crops; but no other book in recent years covers the whole field of commercial tropical fruit growing, and not even any older one covers it so well. Withal, it could be better. There are many typographical errors, often carried over unchanged from the first edition, and there are many errors of fact although they are of very minor importance. It is also evident that the book has never had the service of a competent editor to smooth out some of the rough grammatical constructions.

It is to be regretted that Dr. Chandler has not seen fit to employ hyphens in names involving apple, cherry, plum, etc., when the fruits are not at all related to those well known older species. He notes that the "white sapote" is not related to the sapote, but he does not apply the obvious remedy of writing the name "white-sapote". Much confusion would be avoided if this were done in this case and in Surinam-cherry, sugar-apple, governor-plum, etc. It has come to be the usual practice to write sweetpotato instead of sweet potato, and it is to be hoped that horticulturists will adopt more widely this practice urged nearly 35 years ago in Standardized Plant Names.

It is encouraging to see an eminent pomologist giving more attention to the long years of citrus study by Tanaka, although it is hard to understand why he is always "Dr. Tanaka" in the text while his distinguished opponent is simply "Swingle" as other scientists are also. The only criticism to be made of the reference to Tanaka's work

on classification is that the author missed a fine opportunity to make use of these studies in dealing with the mandarin group and with the calamondin. In both of these Tanaka has given sound reasons for consideration of taxonomic treatment differing sharply from that followed by Swingle.

These faults are very small in comparison with the many excellent qualities of this work, and the reviewer is very glad to have such an up-to-date revision of such a comprehensive and authoritative book to aid his teaching.

H. S. WOLFE

Cotton. H. B. Brown and J. O. Ware. Third Edition. x + 566 pages. McGraw Hill. 1958. $12.00.

A wealth of information pertaining to many phases of one of the world's largest agricultural industries may be found in this volume. While many of the desirable features of the second edition have been retained, the book has been brought up to date through discussions of recent developments in cotton research and technology. Although some of the topics may be of interest primarily to those directly associated with the cotton industry, many of the topics should be helpful to those engaged in related pursuits.

The volume opens with a chapter on the history and scope of cotton and the cotton industry on a world-wide basis with special attention to the development of the industry in the United States. Many of the earliest records of cotton are cited.

Six chapters deal with topics that are of profound interest to those engaged in cotton variety improvement and maintenance work. This rather comprehensive treatment of cotton breeding and related topics reflects the primary interest of the authors who have devoted the major portion of their lives to cotton improvement work. Recent advances in the taxonomy, genetics, and breeding of cotton are reviewed. For example, a modern system of classification which is based on cytological, genetic, geographical, and archeological evidence is discussed in the chapter on taxonomy. Investigations relative to the inheritance of complex characters and other genetic problems are reviewed in the chapter on variation, heredity, and correlation. Current breeding techniques and the practical aspects of variety maintenance and distribution are treated in separate chapters.

Topics directly related to cotton production and cotton production problems are treated in eight chapters. These chapters present discussions of cotton diseases and insects and their control, physiology of the cotton plant, climate and soils for cotton in the United States and some foreign countries, soil fertility and fertilizers, field culture, and harvesting. Recent research information pertaining to these topics is reviewed in each chapter. Even though much interest and research effort have been directed to the problem, the control of weeds with chemicals in cotton is treated rather lightly.

Chapters on subjects relating to cotton ginning, marketing, and manufacturing are of particular interest to anyone associated with these phases of the industry. The rather complex marketing system, including the various types of markets, is discussed in detail. A chapter on cotton ginning traces the harvested seed cotton from the field through the various processing steps to the baled fiber. The fiber is then traced from ginned bales through the various manufacturing stages to the finished fabric. The processing and marketing of cotton seed are discussed under a separate heading. Numerous diagrams, figures, and tables are utilized to supplement the discussion.

The last two chapters treat subjects that are more of general interest. In one chapter the commercial status of cotton is considered. Here are presented some effects on the domestic industry of competition from foreign cotton and synthetic fibers. In the last chapter the authors present numerous tables of statistics that were compiled from different sources. These statistics deal primarily with the production, consumption, and prices of cotton in the United States and foreign countries. Statistics pertaining to competitive fibers are also given.

Although the greater portion of the book pertains to the cotton industry in the United States, much information on the cotton industry in foreign countries is included. In compiling the information use was made primarily of published literature; however, several references to unpublished information are cited. As a whole, the text is well illus-

trated by figures and diagrams and many important tables are included. Although it is doubtful that everyone will be entirely satisfied with the sequence and organization of the material, sufficient cross references are given to enable one to follow a given subject in its entirety. It is believed that this edition will serve as a valuable source of information to the student and professional worker who is in any way associated with the cotton industry.

T. J. STAFFORD
L.S.U.

The Wealth of India. Vol. IV: F-G. Ed. Shri B. N. Sastri. Council of Scientific and Industrial Research. xxviii + 287 + viii pp. 1956.

This volume continues the high standards set by the previous three. A separate volume, issued as a supplement, will contain a monograph on Fish and Fisheries. Included in this volume are the raw materials of plant, animal, and mineral origin. By far the largest discussions deal with the genera *Ficus* and *Gossypium*. Illustrations are good to excellent.

Utilization Abstract

Castor Bean. In the past the raising of castor beans as a regular crop in the United States was rather hazardous economically. Reasons for this were the fluctuating markets and poor varieties. Both of these are now being overcome by research at the U. S. Department of Agriculture, Southern Utilization Research and Development Division. A dwarf, non-shattering variety adapted to machine harvest has been developed. In tests this variety, about three feet tall, produced 2700 pounds per acre in the Texas Panhandle. Remaining problems are: deactivation of toxic principle and removal of allergen.

Qualities

1. Nature of oil—ricinoleic acid component unique among vegetable oils because of hydroxyl group near a double bond.
2. Dehydrated—does not turn yellow on baking or drying.
3. Viscosity and specific gravity high. Viscosity changes are small with temperature changes. Viscosity increased by blowing. Blown oil has good blending properties and low cold test and does not attack rubber gaskets and metal to any great extent.

Uses

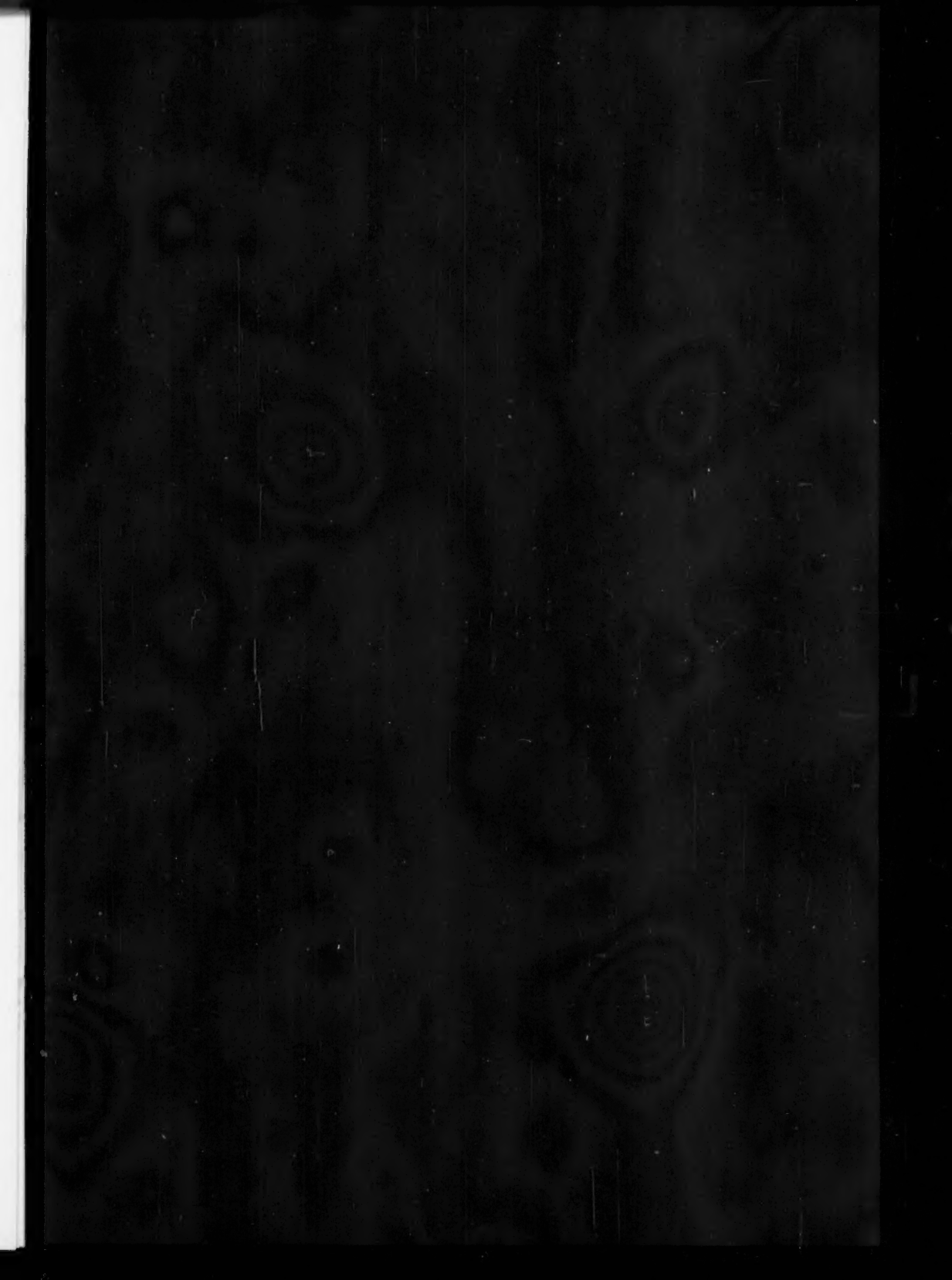
1. Raw oil
   Plasticizer for lacquers
   Leather dressing dope
2. Dehydrated: as a drying oil, good for white or light-colored coatings, gives paints and varnishes flexibility and adhesion to metal.
3. Blown: softening agents for rubber; manufacture of asphalt tile because of superior pigment wetting power; plasticizer in nitrocellulose coatings.
4. Hydrogenated: multi-purpose greases, in waxes, polishes, in the manufacture of carbon paper, candles, crayons.
5. Fractions of castor oil:
   Undecylenic acid—Rilsan, nylon-type product made in France for molding. Bactericidal agent for facial and toilet tissues. Undecylenic acid combined with zinc undecylenate—treatment of athlete's foot. Undecylenic acid and copper salt—remedy for facial infections.
   Heptaldehyde, produced with undecylenic acid by pyrolysis—synthetic flavors and odors. Alcohol with pleasant odor for cosmetics.
   Sebacic acid—Basic ingredient for nylon 6/10, a molding plastic.
   Urethane foams—castor oil has been employed for these to some extent. Used for packing materials, cushioning, filler for interstices where light weight is important.

Processes of Extraction

Imported oil is extracted in two steps: (1) 60 % oil separated by hydraulic pressure giving a light-colored, good grade oil; (2) remainder is solvent-extracted; the yield is

a darker, lower grade oil. Filtration-extraction process is being developed at Southern Utilization Research and Development Division.

Presence of a toxin (ricin, a poisonous protein) and a powerful allergen (a non-toxic protein polysaccharide fraction) are complications in the extraction process. Ricin and the allergin are not carried into oil when oil is properly extracted but remain in the residue or pomace, making the pomace unfit for animal food. The allergin causes difficulty in the extraction plant and surrounding vicinity, in the dust produced, giving residents and workers asthma and other symptoms.

The pomace itself has many possibilities of use, if a good way to remove the ricin and allergen can be found. The protein might be suitable for a variety of industrial uses, such as textile fibers.

A recent estimate by the U. S. Department of Commerce anticipates that a world shortage of 25 million pounds of castor oil is possible by 1961. This does not include 37 million pounds predicted consumption of castor oil by the new industry producing nylon-type fiber in Europe and South America. Authorities close to the castor oil processing industry estimate that this country should be growing about 200,000 acres of castor beans to meet needs of the next three or four years, and this acreage should be expanded to 600,000 acres within the next fifteen years to meet the growing demands of the chemical industry. (Marie A. Jones, *Chemurgic Digest 16*(*10*): *4–7. 1957.*)